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# Journal
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## A RECTANGULAR-COMPONENT TWO-DIMENSIONAL ALTERNATING-CURRENT POTENTIOMETER.*

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AND

EDY VELANDER, A.M.

It is here proposed to describe the construction, mode of operation, and use of a special form of alternating-current potentiometer, particularly adapted to telephonic-frequency measurements, and which gives its readings in two rectangular components of the voltage measured.

*Brief History.*—The name "Electric Potentiometer" was suggested in 1873, by Latimer Clark, for the instrument which he described, as serving to measure continuous-current potential differences, in a paper read in London, January 22, 1873, before the "Society of Telegraph Engineers," the forerunner of "The Institution of Electrical Engineers." This instrument has remained almost unchanged to the present time, and is one of the most valuable measuring instruments which electrical engineering possesses.

An early form of *a-c.* potentiometer was described by Franke in 1891. It employed a small *a-c.* generator with two armature windings mechanically adjustable with respect to a common rotating field; so that both the relative magnitudes and the relative

* Communicated by Dr. Kennelly.

[Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the Journal.]

phase of the two induced *emfs.* at one and the same frequency, could be determined.[1]

An improved *a-c.* potentiometer was described by Dr. C. V. Drysdale[2] in 1909. This instrument has come into fairly extensive use. It measures an *a-c.* potential difference in polar coördinates, over the complex plane; *i.e.,* in size and in slope or phase, with respect to a certain phase standard. Its readings are therefore presented in the general form $E \angle \beta°$, such as $1.500 \angle 125.3°$ volts. Its range, without any auxiliary multiplier, is from 0 to 1.8 volts in size, and 0 to 360° in slope. The range in frequency which it claims is from 25 to 1000 ∾. The Drysdale *a-c.* potentiometer has filled a great need for a laboratory instrument capable of measuring planevector[3] voltages. For many such purposes its use is invaluable. When, however, the source of testing current is an oscillator, and not an alternator, there is a difficulty in using this instrument, because the excitation of the necessary phase-shifting transformer requires more than 60 watts. When an oscillator is used as the source of alternating currents, it is necessary to reduce the power absorbed in the measuring instruments to the lowest available limits. The use of oscillators for such purposes is steadily increasing. It then becomes imperative to adopt such a form of *a-c.* potentiometer as will avoid the use of an electromagnetic phase-shifting device.

Prof. A. Larsen described in 1910,[4] a form of two-dimensional potentiometer, the connections of which appear in Fig. 1. It consists of a non-inductive resistance *AB*, in series with the primary winding of an induction coil *BC*, an adjustable portion of the

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[1] "Die elektrichen Vorgänge in den Fernsprechleitungen und-Apparaten," by Ad. Franke, Berlin, 1891. Thesis towards the Doctorate at Berlin University.

[2] "The Use of the Potentiometer on Alternating-Current Circuits." *Phil. Mag.,* Vol. 17, p. 402, Mar., 1909; also *Proc. Phys. Soc.,* London, Vol. 21, p. 561, 1909; also *The Electrician,* Vol. 63, p. 8, April 16, 1909; and Vol. 71, pp. 687–690, Aug. 1, 1913.

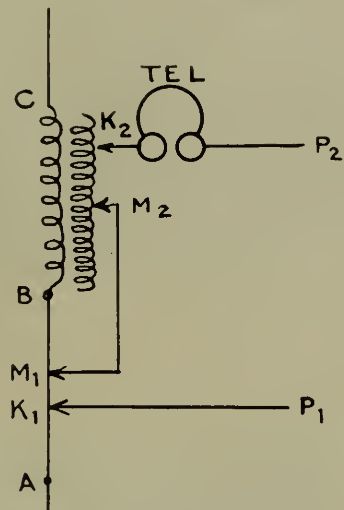
[3] "A planevector" may be defined as a geometrically directed complex quantity in a plane of reference, and subject to the laws of complex arithmetic, as distinguished from a "vector" which is subject to the laws of vector arithmetic and is not necessarily confined to a plane. In this paper, the term "vector" is used as an abbreviation for "planevector."

[4] A. Larsen: "Der Komplexe Kompensator, ein Apparat zur Messung von Wechselströmen durch Kompensation." *Elek. Zeitschrift,* 13th Oct., 1910, Vol. 31, pp. 1039–1041; also *The Electrical World,* Vol. 56, Nov. 3, 1910, pp. 1085–1088.

secondary winding being connected in series with an adjustable portion of the resistance $AB$, so that the vector sum of the resistance drop in $AB$ between $M_1$ and $K_1$, and the mutual reactance drop between $M_2$ and $K_2$, shall be equal to the planevector *p.d.* to be measured, between leads $P_1P_2$, as determined by silence in the telephone.

The construction of a resistance-mutual-inductance potentiometer, on the Larsen principle, was taken up in 1916, in the electrical-engineering research laboratories of the Massachusetts Institute of Technology, by Mr. Alfred E. Hanson, in his thesis

FIG. 1.




Connections of Larsen potentiometer.

work towards a master's degree. In connection with this thesis,[5] the new type of potentiometer here described was designed.

*New Instrument.*—The electrical connections of the new instrument are indicated in Fig. 2, and are in all essentials the same as in Fig. 1. The resistance $OA$ contains 50 ohms, in short coils, of *Ia-Ia* wire, wound both anti-inductively and anti-condensively, and also a short length of slide wire of 0.5 ohm. The mutual inductance coil has two equal copper windings, each having 8.8 ohms resistance at 20° C., and 3.9 millihenrys self-inductance.

[5] "The Design and Construction of an Alternating-Current Potentiometer," by Alfred E. Hanson, September, 1916; a Thesis towards the degree of M.S. in Electrical Engineering at the Mass. Inst. of Technology.

The mutual inductance between the two windings is approximately 3.85 millihenrys. The *p.d.* to be measured is connected to the terminals *pp'*. A vibration galvanometer *V.G.* serves as the balance indicator.

FIG. 2.

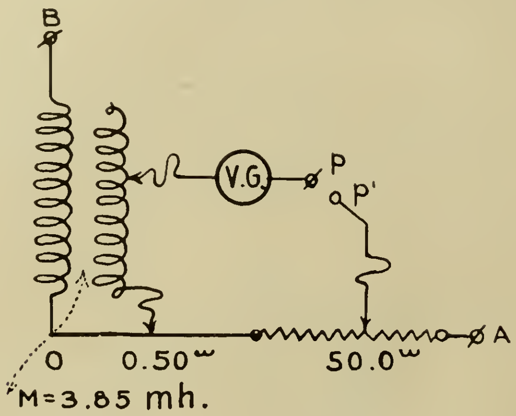


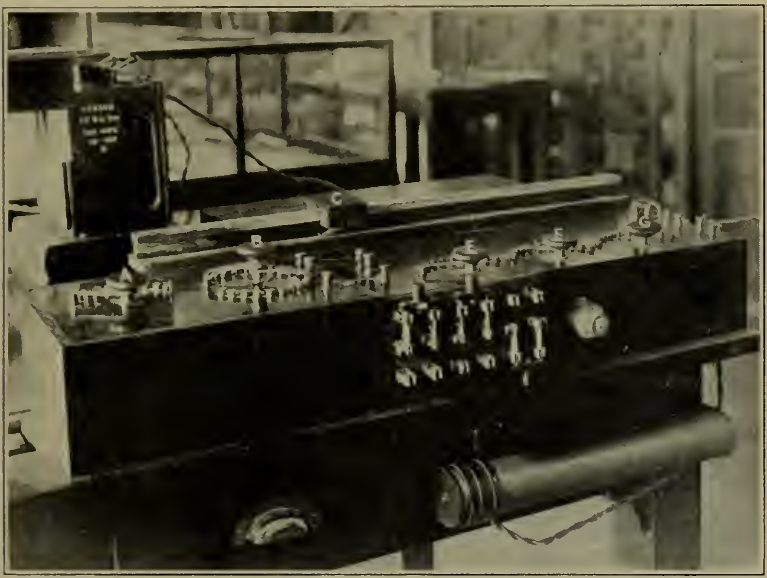

Diagram of connections in new potentiometer.

Fig. 3 shows the general appearance of the Hanson form of potentiometer. The dial switches *A* and *B* control the resistance taps; while the slider *C*, moving over the resistance wire, serves for a fine adjustment of resistance. The dial switches *E*, *F*, and *G*, control secondary taps in the mutual inductor, *E* being for 200 turns per step, *F* 20 turns per step, and *G* 2 turns per step. A fraction of one turn may be added, by turning the handle *f*, as will be described later.

The interior of the mutual inductance box is shown in Fig. 4. The winding is toroidal in form, comprising 41 wooden sectors of suitable taper, as shown in Fig. 5b. The dimensions of one sector appear in Fig. 5a.

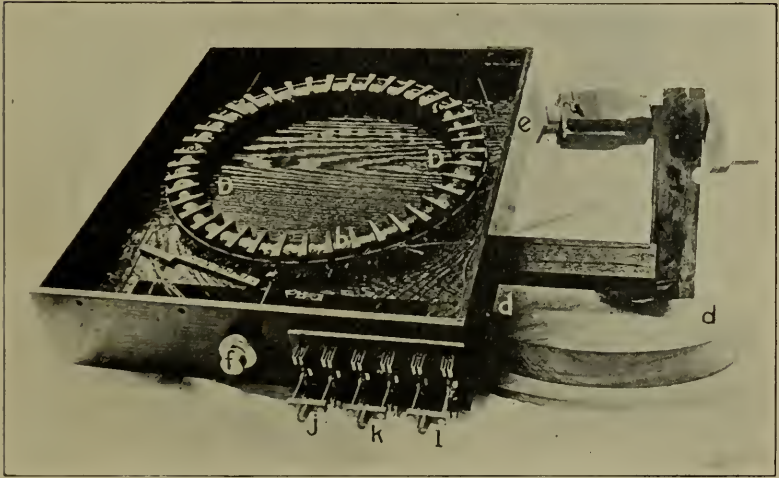
Each sector is first wound with a primary winding of 50 turns of No. 21 B. and S. gage double silk-covered copper wire (bare diam. 0.72 mm.) in 2 layers of 25 turns each. Over this primary winding is laid one layer of varnished cambric insulation. Over this insulation is a secondary winding, also 50 turns of the same size wire, in 2 layers of 25 turns each. In some of the bobbins, taps have to be brought out from the secondary winding. The mean diameter of the toroid is 36.8 cm. When all the sectors are assembled, and connected in series, the winding forms a

Fig. 3.



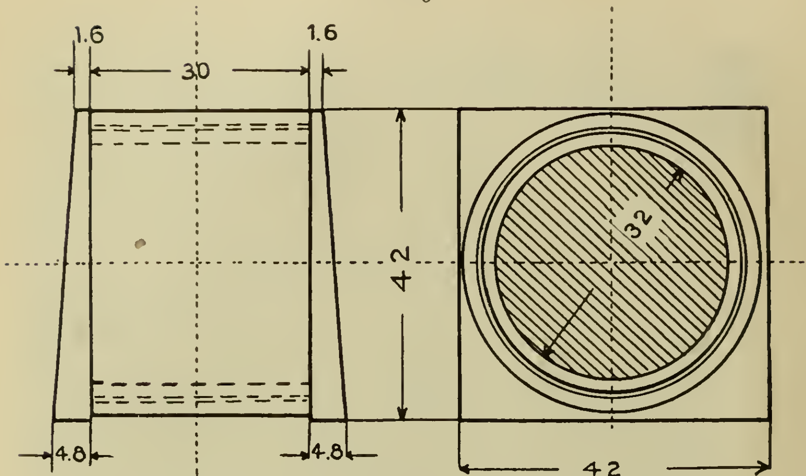
General view of potentiometer.

Fig. 4



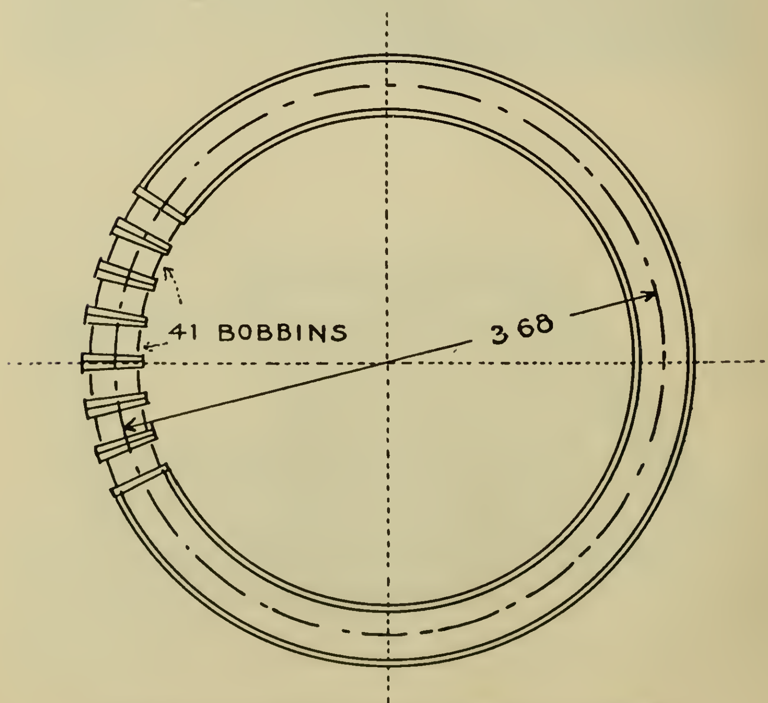

Interior of mutual inductor.

FIG. 5a.




Details of one sector of the mutual inductor. Dimensions in millimeters.

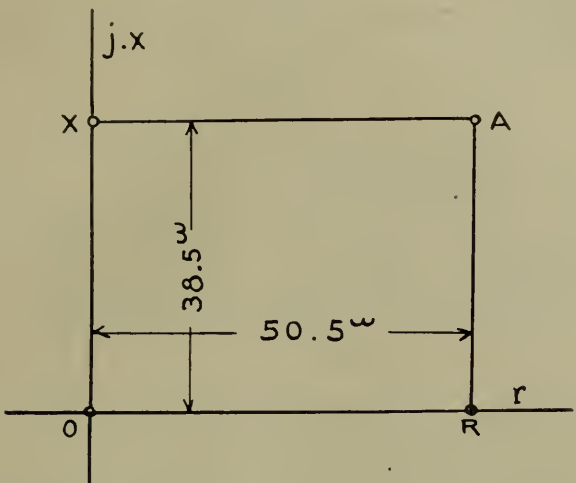
FIG. 5b.




Plan diagram of toroidal mutual inductor. Dimensions in millimeters..

closed circular solenoid with wooden core, devoid of screws or other metallic attachments. A wooden disk *dd*, Fig. 4, serves to support all the individual sectors in their proper places, when glued in position at *DD*. The advantages of the toroidal form of winding are, first, that the external magnetic field is then negligibly small, so that the primary current produces no appreciable stray field in the neighborhood of the apparatus; and second, that with accurate mechanical construction, the mutual inductance between the primary winding and the secondary coils should be proportional to their number of turns. One of the individual wooden

Fig. 6.




Range of impedance covered by the potentiometer, at ω 10,000 radians per second.

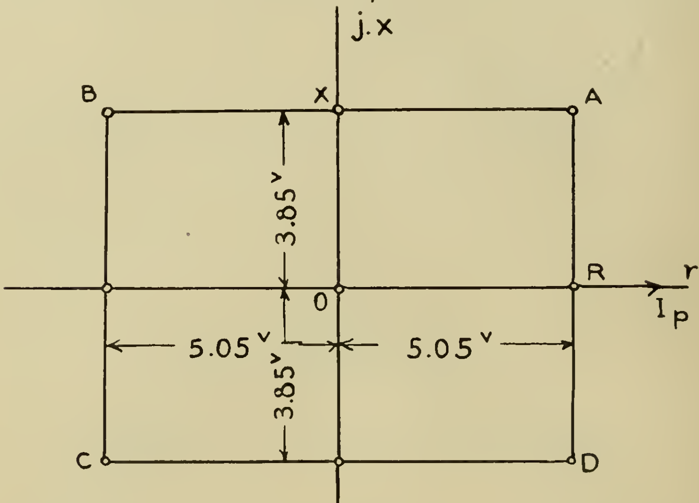
sectors is shown at *e*, held in a winding clamp. The handle *f* connects mechanically, by a spindle, with a single turn of secondary winding, situated in a hollow space at the centre of the core, between two adjacent coil sectors. The range of rotation of *f*, between the limits of $-90°$ and $+90°$, or half a turn, provides the same total change of mutual inductance as one step in the lowest dial.

*Rectangular Range of Instrument.*—Fig. 6 is a rectangular-coördinate diagram, indicating the range in impedance available with the apparatus for potentiometer measurement. The resistance $OR = 50.5$ ohms, and at $\omega = 10{,}000$ radians per second ($f = 1591$ ∽), $j\,M\omega = j\,38.5$ ohms. At any other frequency, the value of the mutual reactance will be varied proportionately.

Any impedance at $\omega = 10,000$, within the area *ORAX* on the diagram, can be covered by the simple series connection of resistance and secondary winding shown in Fig. 2.

Fig. 7 is a similar rectangular coördinate diagram, indicating the range in planevector voltage available with the apparatus for potentiometer measurement. If the *r.m.s.* current $I_P$ supplied to the instrument, is 0.1 ampère, or 100 milliampères, taken at standard phase, and also at the frequency of reference ($\omega = 10,000$), the voltage that can be covered in the first quadrant is

FIG. 7.




Rectangular range of planevector voltage covered at $\omega = 10,000$ and $I_p = 0.1$ ampère.

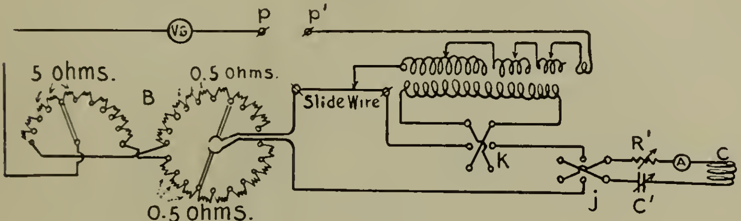
comprised within the rectangle *ORAX*, and so the maximum *p.d.* within reach of the potentiometer is $5.05 + j\ 3.85$ volts. At any other current strength, the voltage developed in the apparatus will be varied proportionately. Any voltage within the field *ABCD*, Fig. 7, can similarly be covered at $\omega = 10,000$, and $I_p = 0.1$ ampère, by suitably reversing either the $R$ or $jX$ components, or both. These reversals are easily made, by means of switches $j$ and $k$, Fig. 4.

*Electrical Connections.*—The full connections of the instrument are indicated in Fig. 8. The coil $C$ is the secondary winding of an oscillator of adjustable frequency, which supplies testing current to the apparatus. The resistance $R'$ and the condenser $C'$ are used to adjust the potentiometer current in size and in slope.

The switch $j$ serves to reverse both $R$ and $jX$. The switch $k$ reverses $jX$ separately. $B$ is a compensating rheostat, so arranged as to keep the total resistance in the circuit constant, while changing the resistance between the tapping points. The unknown *p.d.* is connected to the terminals $pp'$. The vibration galvanometer, by means of which a balance is secured between the adjusted and unknown vector *p.d.s,* is indicated at *V.G.*

*Method of Measurement.*—The vibration galvanometer is at first heavily shunted, and is tuned to maximum response for the impressed frequency. The correct quadrant to employ is first found by using switches $j$ and $k$. Successive adjustments are then made in $R$ and $jX$, until the vibration galvanometer deflection is a

FIG. 8.



Detailed connections of the potentiometer.

minimum. The galvanometer shunt is now reduced, and the adjustments of $R$ and $jX$ repeated, until a sufficiently satisfactory zero balance has been obtained on the galvanometer.

*Absolute and Relative Measurements of P.D.*—Two general methods are available for use with potentiometers such as the one here described; namely,

(1) The method of absolute potential differences, secured by passing a measured constant current through the potentiometer, which current is taken as of standard phase.

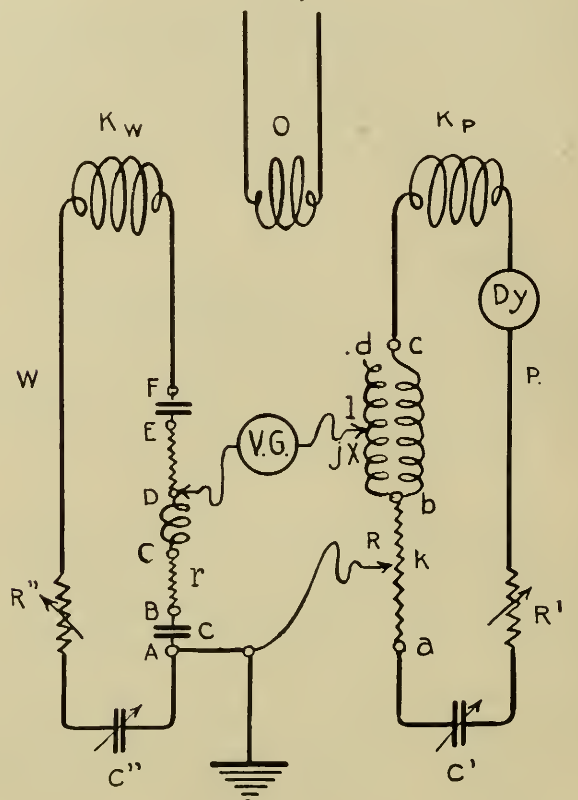
(2) The method of relative potential differences, secured by passing a constant, but unmeasured current, through the potentiometer, whose readings are then uncalibrated, but which become capable of calibration, by being compared with the reading across a certain impedance which is maintained as a standard of reference.

The first method has the advantage that it enables the potenti-

ometer readings to be stated directly in rectangular-coördinate volts. It has, however, the disadvantage of requiring the measurement of the potentiometer current to an even greater degree of precision than that aimed at in the potentiometer work.

In most laboratory measurements of alternating *p.d.*, relative

Fig. 9.




Simplified diagram of connections, showing the rectangular potentiometer *P* arranged for exploration of the potential distribution over the working circuit *W*.

values only are required, and thus it is the ratio of two measured voltages which is of immediate importance. Such ratios can be determined by the relative method, without the necessity of measuring the potentiometer current. The absolute method has, however, to be resorted to, when, as in iron-cored instruments carrying alternating currents, the impedance is a function of the

current strength, and therefore departs from Ohm's law. In all measurements of *p.d.* in circuits which obey Ohm's law, the second or relative method is to be preferred. Both methods of using the new instrument have been tried.[6] In the absolute method, the potentiometer current was measured by a differential dynamometer.[7] This plan was found to work well, although a considerable amount of care was required for the measurement of the potentiometer current. In the progress of the experimental work, however, the relative method was found to be increasingly advantageous.

The essential connections of the second or relative method are presented in Fig. 9. The oscillator coil or source of alternating *emf.* is marked $O$. This coil is inductively connected with each of two circuits; namely (1) the potentiometer circuit $P$, and (2) the tested or working circuit $W$. The $P$ circuit contains the tuning condenser $C'$, and the adjustable resistor $R'$, as well as the potentiometer *abc*. The $W$ circuit may contain any set of apparatus in which potential differences are to be measured. As shown in the figure, the *p.d.* at the terminals $AD$ is being led to the potentiometer through the tuned vibration galvanometer $VG$. In the second or relative method of testing, the drop of potential between terminals $B$ and $C$ on resistance $r$ may be used as the standard *p.d.* Then if the device to be tested in the working circuit is the condenser $c$, the terminals $AB$ can be connected immediately afterwards to the potentiometer. As will be shown later, it is important to maintain a ground connection at the point $A$. Consequently, the drop across any single element, such as $BC$, is obtainable as a vector difference between that across $AC$ and that across $AB$.

Let $r$ be the standard impedance of known slope (which in the case of a strictly non-inductive resistance would be zero) (ohms $\angle$ )
$Z$ be the unknown impedance of the condenser $c$ to be measured (ohms $\angle$ )
$I_P$ be the *r.m.s.* current in the potentiometer circuit (ampères $\angle$ )
$I_W$ be the *r.m.s.* current in the working circuit (ampères $\angle$ )
$R_1 + jX_1$ the reading of the potentiometer across terminals $AC$.
$R_2 + jX_2$ the reading of the potentiometer across terminals $AB$.

[6] "Alternating-Current Potentiometry at Telephonic Frequencies," by Edy Velander; a thesis towards the A.M. degree at Harvard University, June, 1918.

[7] "Precise Measurements of Alternating Currents," by C. O. Gibbon, *Electrical World*, May 11, 1918, pp. 979–981.

Then the drop across the standard resistance $r$ will be

$$I_P(R_1 + jX_1) - I_P(R_2 + jX_2) = I_P(R_0 + jX_0) = I_W r \text{ ..volts } \angle \quad (1)$$

In the $AB$ connection, we have

$$I_P\,(R_2 + jX_2) = I_W Z \text{ ..........volts } \angle \quad (2)$$

Dividing (2) by (1)

$$\frac{Z}{r} = \frac{R_2 + jX_2}{R_0 + jX_0} \text{ ..........numeric } \angle \quad (3)$$

This procedure assumes that $I_P$ remains the same in both tests, and also $I_W$. When, however, a high degree of accuracy is required, this assumption cannot be made. Suppose that in the first test $I'_P$ is the vector potentiometer current, and $I'_W$ the vector working current. Next suppose that when the second measurement is made, both the sizes and the slopes of these currents may have slightly changed, so that $I''_P$ is the new potentiometer current, and $I''_W$ the new working current. Then rewriting (1) and (2) accordingly, we have

$$\frac{Z+r}{r} \cdot \frac{I'_W}{I''_W} = \frac{R_1+jX_1}{R_2+jX_2} \cdot \frac{I'_P}{I''_P} \text{ ..........numeric } \angle \quad (4)$$

If, however, the potentiometer current and the working current vary together, so that the vector ratios remain equal:

$$\frac{I'_W}{I''_W} = \frac{I'_P}{I''_P} \text{ ..........numeric } \angle \quad (5)$$

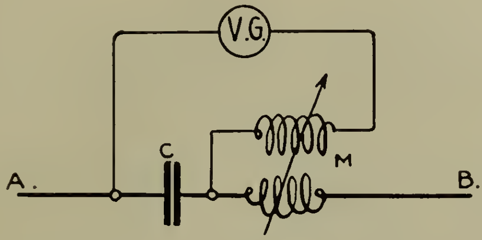
Then equation (3) will still hold. If, then, the mutual inductances between the primary coil, and each of the two secondary coils $K_P$ and $K_W$ remain constant, also the mutual inductance between $K_P$ and $K_W$; likewise the impedance in each of these circuits; then any variation of current in the primary coil, due to unsteadiness in the oscillator, will not affect the vector ratios of equation (5), and will therefore not affect formula (3). If, however, the frequency impressed by the oscillator varies, then the above reasoning will not hold, and the method will be vitiated. It is therefore necessary that the frequency should be maintained constant within satisfactorily close limits. It should be noted that during *a-c* potentiometer tests, no appreciable change should

be made in the load upon the oscillator; because any change in this load produces some corresponding change in the oscillator frequency.

*Frequency Measurements.*—It will be evident from the foregoing, that careful measurements of the impressed frequency are necessary in the use of the *a-c* potentiometer.

Probably the simplest device for the measurement of the impressed frequency is the Campbell condenser and mutual inductance branch circuit [8] of Fig. 10. Here a condenser of $C$ farads is shunted by the secondary coil of a mutual inductance of $M$ henrys and a vibration galvanometer $VG$. One or both of these

Fig. 10.




Campbell frequency-measuring arrangement.

elements is varied, until the galvanometer shows no current. We then have, if $I$ is the vector current in the circuit (ampères $\angle$)

$$jM\omega I + I\frac{1}{j\omega C} = 0 \text{ . . . . . . . . . . . . . . . volts} \angle \quad (6)$$

whence

$$\omega = \frac{1}{\sqrt{MC}} \text{ . . . . . . . . . . . . . . . radians / sec.} \quad (7)$$

Strictly speaking, this zero current in the vibration galvanometer can only be secured if (1) there is no effective resistance in the condenser, and (2) no effective capacitance in the secondary coil. Owing to the great difficulty of securing these conditions, to the necessary degree of precision, a sharp zero balance is hard to obtain. The modification of connections shown in Fig. 11 enables this difficulty to be overcome. A large resistance $R$, of say 2000 ohms, is connected through an adjustable small inductance $l$, as a shunt to both the condenser and mutual-inductance primary. The secondary is led through the vibration

[8] A. Campbell. *Phil. Mag.*, May, 1908, Vol. 15, p. 166.

galvanometer to an adjustable tap on the resistance. If the condenser current is represented by $I_c$ *r.m.s.* ampères $\angle$, and the current in the resistance by $I_R$ *r.m.s.* ampères $\angle$, then with $V_{AB}$ *r.m.s.* volts $\angle$ as the *p.d.* between $A$ and $B$, at balance,

$$I_c = \frac{V_{AB}}{r+j\left(L\omega - \frac{1}{C\omega}\right)} \text{ ........................ ampères } \angle \quad (8)$$

and

$$I_R = \frac{V_{AB}}{R+jl\omega} \text{ ........................... ampères } \angle \quad (9)$$

$r$ being the effective resistance of the secondary winding in ohms. The *p.d.* in the galvanometer circuit will be

$$jM\omega I_c + kRI_R = 0 \text{ ........................... volts } \angle \quad (10)$$

where $kR$ is the resistance included between $B$ and the tapping point. After this zero balance has been obtained, first by assigning $k$ and $C$, with a final adjustment in $M$ and $l$, we have

$$\omega = \frac{1}{\sqrt{C\left(L+\frac{M}{k}\right)}} \text{ ...................... radians / sec. } (11)$$

with the further condition that $l$ has had to be adjusted to

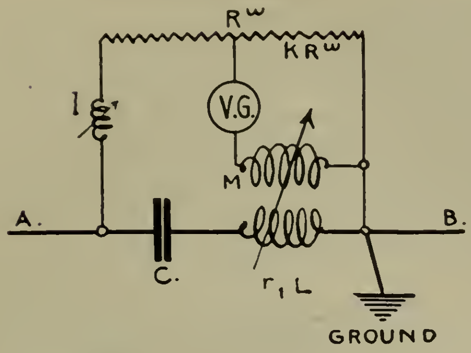
$$l = CRr\left(1+\frac{kL}{M}\right) \text{ ........................... henrys } (12)$$

This method enables a sharp balance to be obtained at the expense of the additional adjustments. Moreover, since $1/k$ may conveniently be made a large number, $C$ and $M$ can both be kept reasonably small, even at low frequencies.

The same connections are presented in Fig. 12, under the form of a generalized Heaviside bridge. Formulas (8) to (12) apply equally well to this case.

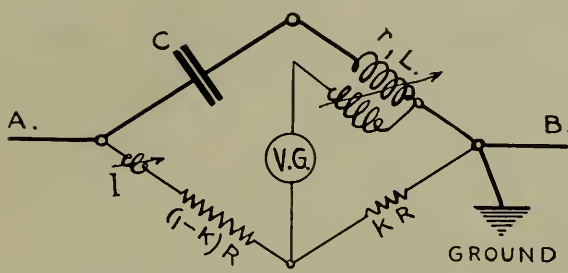
In both Figs. 11 and 12, a ground connection is indicated in the frequency measuring set, at the point $B$. As will be mentioned in connection with sources of error in the use of the potentiometer, the selection of a proper ground point is vital to the accuracy of the measurements. At frequencies higher than, say, 100 cycles per second, parasitic alternating currents, due to distributed capacitance in the apparatus, play an increasingly prominent part. At very high frequencies, such parasitic currents may even swamp the working current. Either the point $A$, or the point $B$ may be grounded in Figs. 11 and 12; but prefer-

FIG. 11.



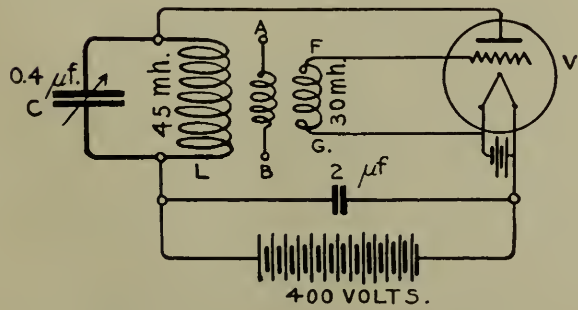

Preferred modification of frequency measurer.

FIG. 12.




Bridge arrangement of connections in Fig. 11.

FIG. 13.

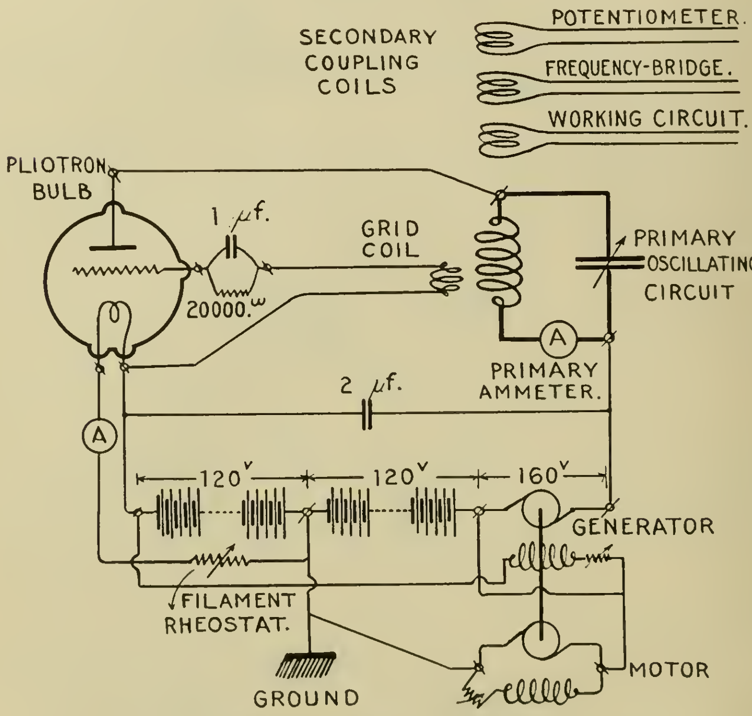



Pliotron connections; skeleton plan of connections.

ably *B*, owing to the preponderating distributed capacitance of the mutual inductor.

*Oscillator.*—A convenient set of vacuum-tube generator connections appears in Fig. 13. *V* is a 3-electrode vacuum-tube of a pliotron oscillator or similar type, with its plate, grid and filament. The main oscillation circuit consists of the adjustable condenser *C* and inductance *L*. The grid-coil secondary winding *FG* supplies the oscillating excitation to the grid. The secondary

Fig. 14.




Arrangement of the pliotron as a generator.

winding *AB* may be connected to the potentiometer circuit. Several such secondary coils may be used. The continuous *emf.* may be supplied by a small dynamo generator. If possible, this generator should be driven by a motor actuated by storage battery for steadiness of action. An auxiliary condenser of $2\mu f$ serves as a high-frequency bridge across the inductance of the generator.

A more detailed set of connections, showing an actual arrange-

ment employed, appears in Fig. 14. In this case, 240 volts of continuous plate *emf*. was derived from a storage battery, and 160 volts from a generator which was storage-battery-motor driven.

A Vreeland oscillator was also used in the earlier measurements. This apparatus is too well known to need special description. With the Vreeland oscillator employed, the available range of frequency, without external auxiliary apparatus, was from 400∽ to 2500∽. With the pliotron oscillator, the available range of frequency was limited only by the capacitances and inductances employed in the oscillation circuit.

*Vibration Galvanometer.*—In nearly all of the measurements made with the apparatus, a Duddell bifilar vibration galvanometer, adapted for use up to a frequency of 2000∽, was employed as the balance detector. This served the purpose satisfactorily when properly tuned to the impressed frequency. When *p.d.* measurements are made upon apparatus of high internal impedance, a detector of greater sensitivity and corresponding impedance would be preferable. A pair of head telephones of suitable impedance were found to work well in such cases. A crystal detector with *d-c.* galvanometer was also used successfully.

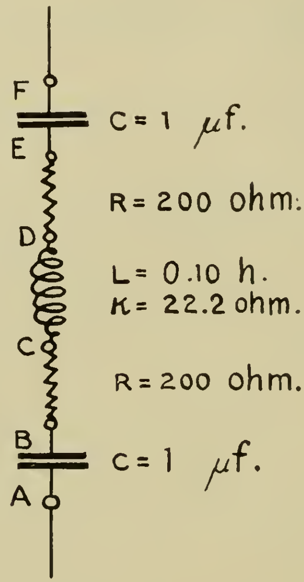
*Example of the Use of the Instrument in a Simple A-C. Circuit.*—As an example of the measurements that may be made with the instrument, we may consider the simple series circuit $ABCDEF$ in Fig. 15, consisting of a fixed mica condenser $AB$ of 1.0 microfarad, in series with an anti-inductive metallic resistance $BC$ of 200 ohms, followed by a non-ferric inductance $CD$ of 100 millihenrys and 22.2 ohms, followed again by an anti-inductive resistance $DE$ of 200 ohms similar to $BC$, and finally by a second mica condenser $EF$ of 1.0 microfarad.

The electrical connections for exploring the potentials along the work series $AF$, Fig. 15, are indicated in Fig. 9. When using the absolute method, the differential dynamometer, $Dy$, measures the *r.m.s.* alternating current strength supplied in the potentiometer circuit, and thus furnishes the voltage scale $E = IR + jIX$, obtained for any reading of $R$ and $jX$. Fig. 16 shows the results actually obtained in this way, at an impressed frequency of 500∽, with a current of 0.020 ampère in the potentiometer circuit. The grounded point $A$ was kept fixed, and measurements were made by shifting the lead of the tuned vibration galvanometer along the points $B$, $C$, $D$, $E$ and $F$ in succession. These vector *p.d.s* are indicated in Fig. 16 by the vectors $AB$, $AC$ . . .

*AF*, respectively. The straight lines connecting the adjoining pairs of points *BC, CD, DE* and *EF* on the diagram, then become the inferred vector potential drops in the successive elements of the circuit, all presented to the particular phase of the potentiometer current as standard.

It will be observed that the lines *BC* and *DE* are parallel. The direction of these lines shows the phase of the current in the working circuit, assuming that the anti-inductive resistances *BC* and *DE* may be regarded as pure resistances, at the test frequency

FIG. 15




Simple series circuit explored.

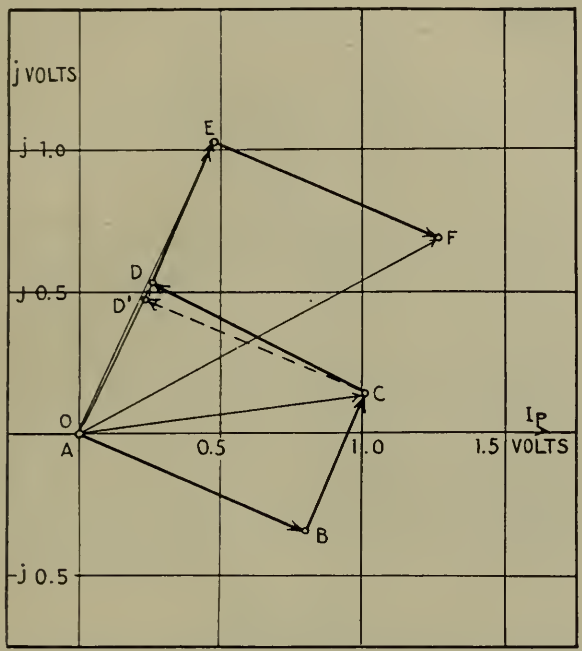
of 500 ∿. The lines *AB* and *EF* on the diagram are also parallel to each other, and are perpendicular to the lines *BC* and *DE*. This shows that the voltages at the terminals of the condensers lag substantially 90° behind the current in the working circuit, according to the regular theory. The line *CD* is the drop in the inductance coil, and may be analyzed into two mutually perpendicular components; namely, *D'D* in phase with the current, due to the presence of resistance, and *CD'* in leading quadrature with the current, due to the inductive reactance of the coil.

If we replot the diagram to working-current standard phase,

as in Fig. 17, we rectify the diagram by a virtual rotation of approximately 65° in the clockwise direction. The various voltage drops are then read off, to rectangular coördinates, in the customary manner.

The diagram of Fig. 17 gives a correct presentation of the voltage drops in each or any series combination of the elements in the working circuit, provided that the potentiometer current $I_P$ has been measured. In order to evaluate the impedance of the

FIG. 16.

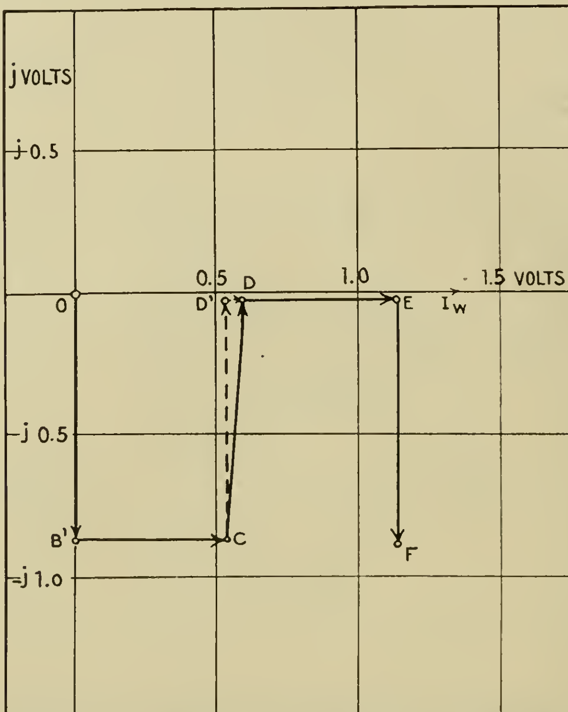



Distribution of planevector voltage along series $AF$, Fig. 15, at 500 ∽, to potentiometer current standard phase.

corresponding elements, it becomes also necessary to know either the magnitude of $I_W$, the working current; or, the vector impedance of one of the elements. Thus, if the resistance $BC$ is a standard resistance of 200 ohms, the scale of the entire diagram can be interpreted in ohms. It should be observed that the measurement of $I_P$, the potentiometer current, with $R$ and $jX$, is insufficient to determine the impedances of the elements in the working circuit, and that while it would be possible to measure both $I_W$ and $I_P$, this double operation becomes burdensome and

unnecessary, so that the use of the instrument naturally leads to the relative method of measurement, in which no current strength has to be determined, but a standard impedance—preferably a standard pure resistance—is included in the working circuit. Measured potential drops on unknown impedances are then referred to the measured drop on this standard, as a working unit.

FIG. 17.




Distribution of planevector voltage in Fig. 16, referred to working current standard phase.

*Sources of Error and Their Elimination.*—It is impossible to work for any length of time with any *a-c.* potentiometer at a telephonic frequency, without encountering discrepancies in the measurements, which are attributable to the well-known disturbance from parasitic currents in the distributed capacitance of the tested apparatus. The first step in the elimination of these superposed parasitic currents is to ground a suitable point in the working circuit, so as to bring that point to zero potential, and prevent the distributed capacitance in the immediate neigh-

borhood of that point from producing a parasitic condenser current. In general, the ground should be established at one end of the range of the elements in the working circuit to be measured. As an example, Fig. 9 shows a ground established at the point $A$.

Suppose that the ground is established at the junction $B$ of two impedances $AB$ and $BC$ to be compared, such as $Z_1$ and $Z_2$ in Fig. 18, and that $I_W$ is the working current in the absence of distributed capacitance, and therefore equal in the two impedances.

Fig. 18.

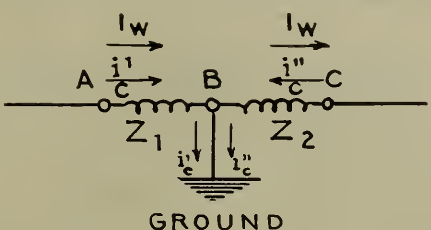



Diagram illustrating the effect of improper grounding.

dances. The current $i'_c$ in $Z_1$ represents a small parasitic current of a certain magnitude and phase escaping to ground at $B$, while the current $i''_c$ in $Z_2$ is a similar small parasitic current which, in general, will have a different magnitude and phase, also escaping to ground at $B$. The resultant working currents in the two impedances will then be the vector sums $(I_W + i'_c)$ and $(I_W - i''_c)$ ampères, respectively. The ratio of the potential drops in the two impedances will then be

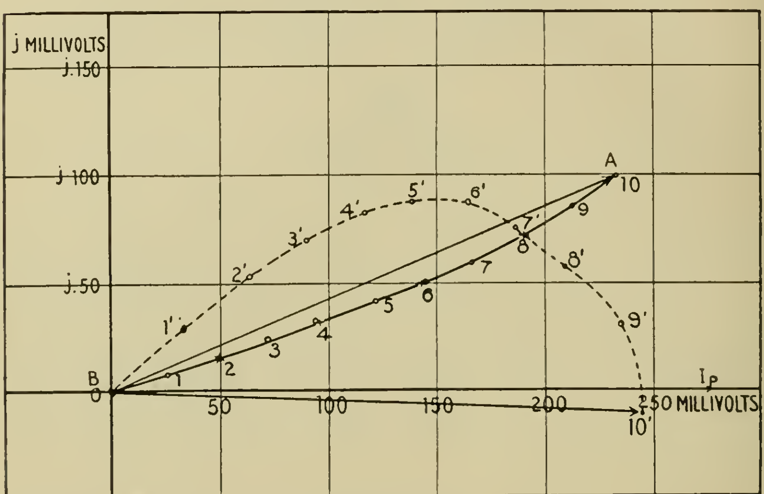
$$\frac{(I_W + i'_c)Z_1}{(I_W - i''_c)Z_2}$$

which, in general, will differ from the required ratio, $\frac{Z_1}{Z_2}$ by an unknown amount.

In cases where the quantity to be determined is a potential difference distribution, rather than an impedance comparison, the importance of a proper grounding point in the working circuit is equally great. It is evident that, as a general rule, during a set of *p.d.* measurements on the same working circuit, the grounded point should not be shifted. This is for the reason that when the ground connection is shifted, the potential of all points along the circuit with respect to the ground is varied, thereby changing the entire distribution of parasitic currents.

An experimental example of the effect of shifting the ground connection in a working circuit appears in Fig. 19. Here a standard resistance box of 100,000 ohms, in 10 series coils of 10,000 ohms each, was inserted in the working circuit, as shown in Figs. 20a and 20b. In Fig. 20b, the vibration galvanometer connection to the potentiometer is carried permanently to the end $B$ of the resistance box. Since it is manifestly inadmissible to establish a ground connection on this lead, as it would bring parasitic current directly through the galvanometer, the ground has to be established at $t$, the travelling lead to the potentiometer.

FIG. 19.



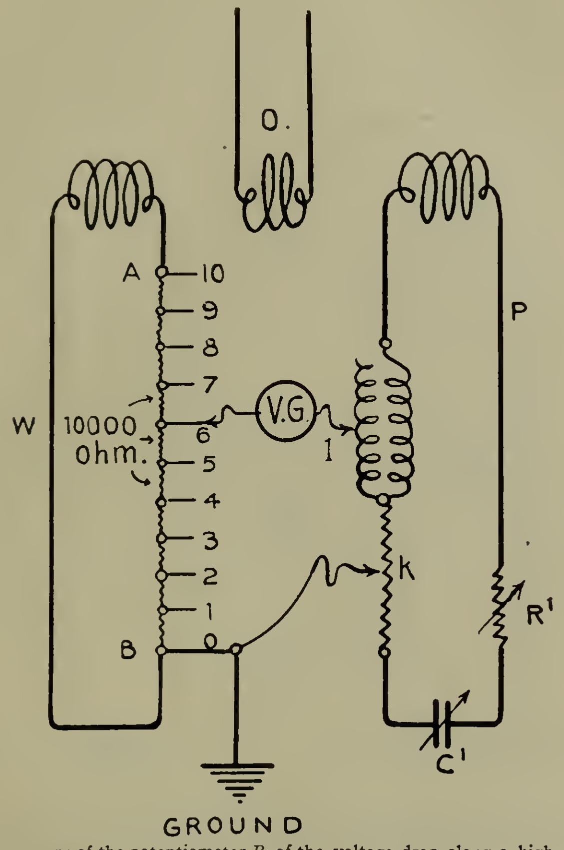

Distribution of planevector voltage along 100,000-ohm resistance box. Small circles indicate observed values, crosses indicate computed values, assuming that each section of the box subtends a hyperbolic angle of 0.08 $\angle 45°$ hyp. radian.

This involves, however, a change in the distribution of potential and capacitance current at each change in the position of $T$. The result is shown in the broken curve 1′, 2′, 3′ of Fig. 19. The curve of *p.d.* between $A$ and $B$, Fig. 20, should evidently be a uniform straight line $O10'$ in Fig. 19. The presence of the changing parasitic current distribution appears to have been responsible for the erratic curve shown. Assuming that the *p.d.* across the entire resistance box is correctly represented by the vector $O10'$, Fig. 19, then all of the intermediate *p.d.s* should be

situated along this straight line; whereas the actually measured *p.d.s* from *O* to the successive points 1, 2, 3, etc., Fig. 20b, follow the bending line 1′, 2′, 3′ . . ., etc.

The connections were then changed to those of Fig. 20a, in which the ground connection is kept fixed at *B*, and the travelling

FIG. 20a.



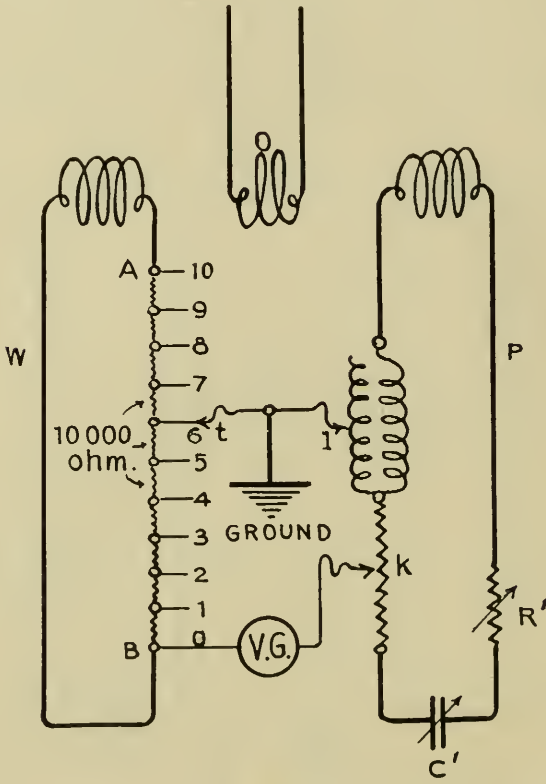

Exploration by means of the potentiometer *P*, of the voltage drop along a high-resistance box *A B*, of 100,000 ohms. Note correct position of ground-connection at *B*.

lead contains the vibration galvanometer. The corresponding vector curve of *p.ds* is shown at 1, 2, 3, 4, Fig. 19, and is a much closer approximation to a straight-line vector *OA*, representing the *p.d.* over the entire resistance. This curve resembles in form that presented by an artificial cable when an alternating *emf.*,

such as *OA* Fig. 19, is impressed on the sending end, while the distant end is grounded. The curve indicates that each section of the box subtends a small hyperbolic angle.

*Applications of the New Form of A-C. Potentiometer.*—A large field of experimental investigation in the laboratory lies

FIG. 20b.




Incorrect arrangement of ground-connection giving rise to the erroneous results 1′, 2′, 3′ . . . . . . in Fig. 19.

open to the *a-c.* rectangular potentiometer. The power it consumes is a fraction of 1 watt, while its range of voltage is extensive. It enables the vector *p.d.* on different parts of an alternating-current instrument, or on different sections of an alternating-current line, to be measured conveniently. The results are also of considerable educational value to the student. It is pro-

posed to communicate in another paper a number of the results obtained experimentally at various telephonic frequencies.[9]

It should be pointed out that the degree of precision obtainable with the instrument, although very satisfactory from an alternating-current standpoint, is not to be compared with that readily obtainable from the *d-c.* potentiometer. This relatively low precision is attributable to parasitic currents from distributed capacitance, and also to stray alternating magnetic fields. If these two sources of error could be eliminated, the precision of the instrument might be of the same order as that of the *d-c.* potentiometer.

*Suggestions for Improvements in Construction.*—A weak point in the design of the new instrument is the relatively high internal capacitance between the primary and secondary windings of the mutual inductor, which, at high frequencies, tends to produce impurity in the vector mutual reactance $jX$. This defect could be reduced by increasing the insulating spacing between the concentric primary and secondary windings on the toroid. At 2000∽, the discrepancy due to this mutual capacitance appears by measurement, in this instrument, to be $(0.25 + j1.2)$ per cent. in voltage, but rapidly diminishes as the frequency is reduced. There is also a weak point in the toroidal form of mutual inductor, that although there is negligibly small stray alternating field produced in the apparatus by an exciting primary current, yet the secondary winding is not exempt from the influence of stray magnetic fields from external sources at testing frequency. Precautions should therefore be taken to remove the apparatus from the vicinity of alternating magnetic fields.

## SUMMARY.

(1) The principle of the *a-c.* rectangular potentiometer here described is not new, but the form of the instrument appears to be new.

(2) By the use of this instrument, alternating *p.d.s* can be measured, to rectangular coördinates, up to at least 2000∽, with only a small expenditure of power.

(3) The use of the instrument shows the marked influence of distributed capacitance in *a-c.* apparatus, and the importance of reducing this disturbing effect when measurements are made.

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[9] *Proc. American Philosophical Society*, 1919.

(4) The importance of a proper ground connection in the working circuit is emphasized.

(5) The *a-c.* rectangular potentiometer escapes the necessity of measuring the strength of alternating current in either the potentiometer circuit, or the working circuit, provided that the relative method is used, and that the impressed frequency is maintained constant.

(6) Owing to the effects of distributed capacitance, the voltage distribution in a simple series resistance box, carrying alternating currents, fails to follow a vector straight-line law. The deviation tends to increase with the impressed frequency.

(7) The importance of reducing the mutual capacitance between the concentric primary and secondary windings of the toroidal induction coil, at high frequencies, is emphasized as the result of experimental tests.

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**Analysis of Statically Indeterminate Structures by the Slope Deflection Method.** M. W. WILSON, F. E. RICHART and CAMILLO WEISS. (*Bulletin No. 108, Engineering Experiment Station, University of Illinois, 1919.*)—In recent years rectangular steel frames with riveted joints have been used, and many types of monolithic reinforced concrete frames have been developed. The use of statically indeterminate stresses cannot, accordingly, always be avoided. Structures are frequently made of an indeterminate type to secure economy of material. It is felt that analyses of statically indeterminate structures are desirable since such information will do much to inspire confidence in the reliability and in the economy of such structures.

An investigation of statically indeterminate structures has been conducted by the Engineering Experiment Station of the University of Illinois to obtain a convenient method of analyzing the moments, stresses and deflections for a number of typical structures. The analyses were based upon the assumptions that the connections are perfectly rigid, that the length of a member of a rectangular frame is not changed by axial stress and that the shearing deformation is zero. The method has been explained in sufficient detail to enable the designing engineer to use it in the solution of his problems. It is believed that the fundamental principles presented may be readily coördinated with the ordinary principles of mechanics so that the more complex and even the simpler problems may be studied from a new viewpoint.

# THE PHENOMENA OF DRYING WOOD.*

## An Analysis of the Internal Stresses Which Occur in Wood During the Progress of Drying from the Green Condition, with a Brief Discussion of the Physical Properties Which Affect These Stresses.

BY

HARRY D. TIEMANN, M.E., M.F.

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### INTRODUCTION.

But little knowledge exists, either among skilled artisans working with wood or among scientists, concerning the phenomena which take place accompanying the extraction of moisture from the green condition to the perfectly dry state. The U. S. Forest Service has devoted years of study to this subject and has derived many interesting facts and conclusions, although there is still much to be learned.

I will attempt to present here a complete summary of the main facts as far as known, together with a brief attempt to show the relationship of the stresses mathematically. Just how the water passes through the wood, from the centre to the surface, whether by capillary action, flow, or by repeated vaporization and condensation or a combination of these is still unknown, and I will not attempt at the present writing to burden the reader with a discussion of the theory concerning this process. Suffice it for the present to accept the fact that this action must take place in some manner in order that a solid block of wood dry. The physical factors influencing this transfusion of moisture, however, must needs be considered.

In order to get a clear conception of what takes place during this transfusion and evaporization of moisture, a knowledge of the wood substance itself and its relationship to moisture is absolutely essential. I must, therefore, prevail upon the patience of the reader by first setting forth as briefly as possible a description of this complex material with which we have to deal.

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* Communicated by the Director of the Forest Products Laboratory, Madison, Wisconsin.

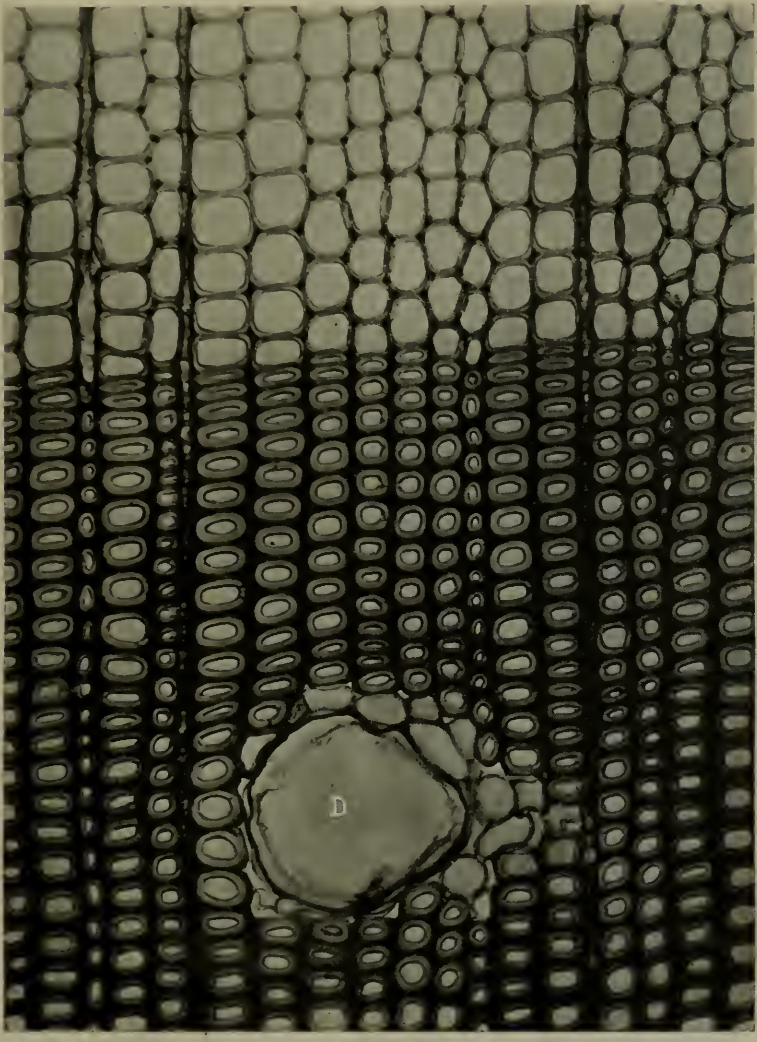
THE WOOD SUBSTANCE.

The substance of which wood is composed being organic is, therefore, very complex. It is half again as heavy as water, with a specific gravity of 1.56. It is thought to be built up of small particles closely laid together, the interstices being capable of filling up with moisture. The foundation part of this substance is known as cellulose. Cotton is almost pure cellulose, but in wood there is another material combined with the cellulose called lignin. This has never been isolated by itself, but is known only in combination with other substances. Just how it is combined with the cellulose is not well known. It adds to the strength of the cell walls and gives them a color. The elements of which cellulose is composed are combined in the same proportion as in starch, to which it is closely allied, although the molecule is differently arranged. Both are represented by the formula $(C_6H_{10}O_5)_n$, the hydrogen and oxygen being combined in the same proportion as in water.. Sugars, gums, and resins are all closely related and it is probable that the living protoplasm is capable of transforming one into the other by the addition or subtraction of water from the molecule. This accounts for their common occurrence in living trees. For example, addition of hydrogen and oxygen in the proportion of water to the molecule of cellulose yields cane sugar, $2(C_6H_{10}O_5)+H_2O=C_{12}H_{22}O_{11}$. This conversion, however, does not take place in the simple manner indicated by the above equation, but the equation is given in order to show the relationship.

THE STRUCTURE OF WOOD.

Wood is made up of minute cells, arranged somewhat as the cells in a honeycomb except that the cells in wood are very much longer in proportion to their width than in a honeycomb and they are not as uniform. In the "softwoods" (gymnosperms) the vertical cells are fairly uniform in shape and size but in the hardwoods (angiosperms) they vary greatly, some being fifty times as wide as others, the wide ones being termed "vessels" and the narrow ones "wood fibres." Interspersed between these vertical cells and fibres and lying in a horizontal radial direction are the medullary rays, appearing as the "silver grain" on quarter-sawed oak. The medullary rays are composed of short, blunt, thin-walled cells, similar to pith tissue, and are shaped like two-edged swords set edgewise.

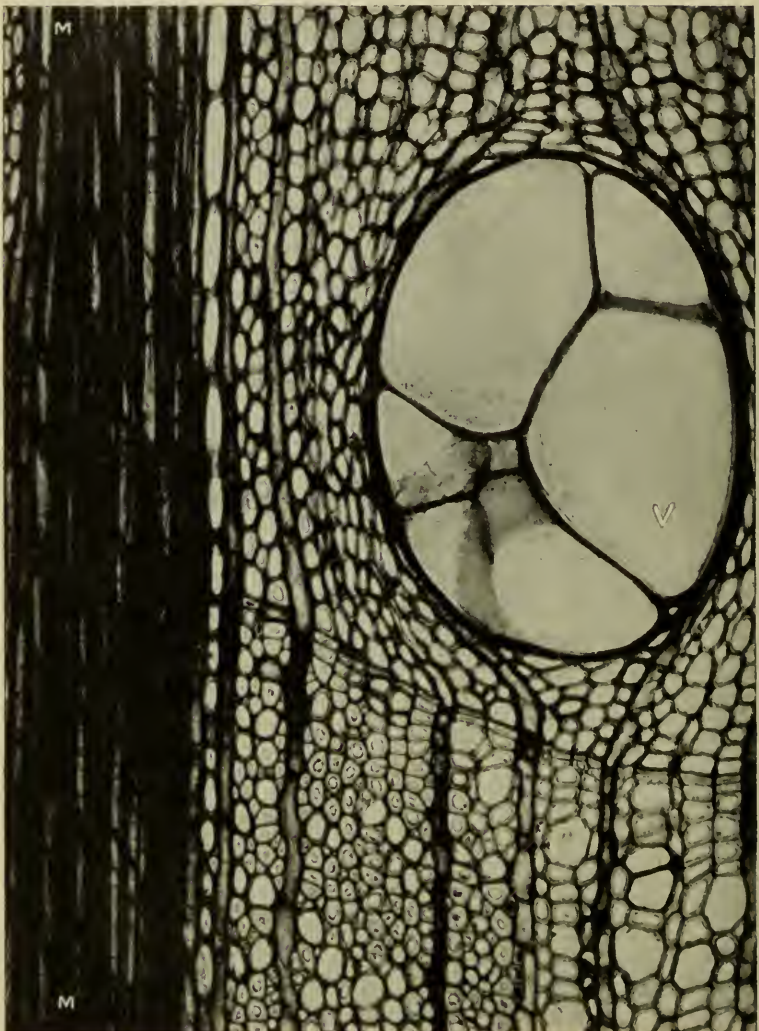
FIG. 1.



Microscopic section of a Gymnosperm ("Softwood"), a piece of shortleaf pine (*Pinus echinata*); at junction of two annual rings. The vertical lines are the medullary rays (radial). The centre of the tree is below. A resin duct D is visible in the "summerwood." Magnified 250 diameters.

Fig. 1 is a cross-section of a gymnosperm (*Pinus echinata*), and Fig. 2 of an angiosperm (*Quercus minor*), both magnified the same amount, 250 diameters.

FIG. 2.




Microscopic section of an Angiosperm ("Hardwood"), a piece of post oak (*Quercus minor*) at junction of the annual rings. An open vessel or "pore" V is shown in the springwood and a large medullary ray M (radial) on the left. The centre of the tree is below. Magnified 250 times.

**THE FIBRE SATURATION POINT.**

Water exists in green wood in two forms: As liquid water contained in the cavities of the cells or pores, and as "imbibed"

or hygroscopic water intimately absorbed in the substance of which the wood is composed. The removal of the free water from the holes or pores will evidently have no effect upon the physical properties or shrinkage of the wood,[1] but as soon as any of the "imbibed" moisture is removed from the cell walls shrinkage begins to take place and other changes occur. The strength also begins to increase at this time. The point where the cell walls, or wood substance, become saturated is called the "fibre saturation point," and is a very significant point in the drying of wood. In some cases the free water can be readily removed by heating above the boiling point, but in many cases this would injure the wood, and as a rule the water contained within the cells themselves can not be forced out in this manner, only that from the open vessels or pores (see Fig. 2) passing off in vapor. The chief difficulties, however, come in evaporating the free water where it has to be removed through its gradual transfusion through the cell walls instead of by boiling. The problem arises in the danger of drying the surface below its fibre saturation point while free water still remains in the interior. As soon as the imbibed moisture begins to be extracted from any portion shrinkage begins and stresses are set up in the wood which tend to cause checking. The fibre saturation point lies between moisture condition of 25 and 30 per cent. of the dry weight of the wood, depending on the species.[2] Certain species of eucalyptus, oak, and probably other woods, however, appear to be exceptional in this respect in that shrinkage begins to take place at a moisture condition of 80 to 90 per cent. of the dry

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[1] An exception to this statement occurs in certain species, notably in western red cedar (*Thuja plicata*) and in redwood (*Sequoia sempervirens*), in which a collapse of the cell walls takes place in spots or bands during the evaporation of the free water. This collapse occurs only in excessively wet regions and when the wood is dried at too high a temperature. The explanation of this peculiar phenomenon appears to be that the cell walls, which are practically impervious to air while wet, but through which water may readily pass, become soft and plastic when heated. Under this condition those cells which are completely full of water to start with are subjected to an internal suction or tension produced by the depletion of the water in the cavity by its evaporation through the cell walls. The cells then collapse like rubber tubes, one layer after another.

[2] See Forest Service Circular 108—The Effect of Moisture on the Strength of Wood.

weight. It is possible that this apparent shrinkage may in reality be a form of collapse.

### SHRINKAGE AND MOISTURE.

Wood in the living tree contains a great amount of moisture, varying from 30 per cent. in the heartwood of some conifers to over 200 per cent. of the dry weight in some of the hardwoods. This moisture must be removed before the wood is fit for use for most purposes.

Wood shrinks differently in different directions—as a rule it may be considered to shrink twice as much circumferentially as it does radially and about one-fiftieth as much longitudinally. Shrinkage continues until this substance is perfectly dry ("oven dry"), and the wood begins to swell again by absorption of moisture as soon as it is exposed to moist air. Alternate shrinking and swelling is inevitable with corresponding changes in the relative humidity of the surrounding air. This causes the so-called "working" of the wood. Different species vary greatly in this respect.

Now in the living tree the wood is always above its fibre saturation condition, so that dry wood may be looked upon as in a unique condition, in that it has never been dry since it was first formed.

### DRYING.

The operation of removing the moisture from wood does not consist simply of evaporation. This, of course, would be merely a matter of supplying the necessary heat and removing the excess vapor. Wood is a complex substance and the removal of the moisture is accompanied by physical and chemical changes.

In order to pass out from the interior of a board or timber the water must ordinarily pass transversely from cell to cell and evaporate from the surface. It is true that it can travel lengthwise very much more rapidly, as is evidenced by the end checking of lumber, but end drying cannot be counted upon for removal of moisture from the centre of a long stick. This process of transfusion from cell to cell is very slow, so that it takes one-inch boards from six months to three years to thoroughly air dry, according to the species, the amount of water they contain when green, and the conditions of drying, such as method of piling, air conditions, etc. Even then, unless it is in an exceedingly dry

climate, the wood will rarely dry below 12 to 14 per cent. For thoroughly dry wood this must be supplemented by kiln drying.

Were it not for the unequal shrinkage and the slow rate of transfusion of the moisture from cell to cell, the kiln drying of lumber would present no more difficulty than the drying of wet cloth or clay. The problem would be merely one of conducting the requisite amount of heat to the material to supply that required for vaporization, which at 163° F. is 1000 British thermal units of latent heat plus a small additional amount (about 30 B.T.U. per pound of dry wood [3]) required to overcome the attraction of the hygroscopic material for the moisture. By use of a low pressure or a temperature higher than the boiling point the moisture would pass off directly in proportion to the quantity of heat supplied.

## PROPERTIES OF THE WOOD WHICH AFFECT DRYING.

In the first place let us consider the physical properties of the material, which must be recognized in order to intelligently study the drying problem. Different species differ very greatly with respect to the relative proportions of these properties, but all possess them more or less.

1. The rate of transfusion of moisture through the wood substance has already been discussed. It is very slow in some woods, as oak, and fairly rapid in others, as pine. It is supposed that the rate is accelerated by increase in temperature.

2. Wood shrinks differently in different directions, and shrinkage usually begins only when the drying falls below the fibre saturation point, although with some species, as *Eucalyptus globulus* and some oaks, the point is not well defined.

3. Wood substance becomes soft and plastic at high temperature under moist conditions. The effect of temperature upon plasticity varies greatly with different species, some, as western red cedar, redwood, and eucalyptus, becoming excessively soft even as low as 150° or 170° F.

4. Cohesion between the fibres easily breaks down with increase in temperature in such woods as western larch, and the southern swamp oaks, thus permitting internal stresses to cause checking with great readiness.

5. Tendency to warp is due to a warped direction of the fibres. Cupping of slab cut boards is simply explained by geometrical

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[3] Frederick Dunlap, Forest Products Laboratory.

relations due to unequal shrinkage radially and circumferentially.

6. Wood shrinks more when dried slowly under moist conditions than when dried rapidly, and the higher the temperatures under moist conditions the greater the shrinkage.

FIG. 3.

Badly honey-combed oak wagon felloes. Produced by too severe casehardening in drying.

7. Excessive drying causes brittleness.

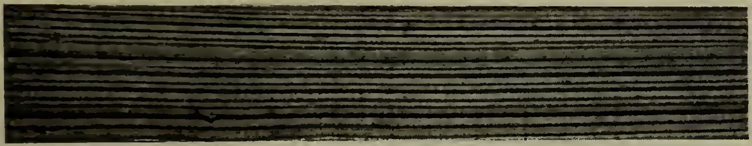
8. Wood absorbs or loses moisture in proportion to the relative humidity of the air, varying slightly according to the temperature. This property is known as " hydroscopicity."

9. Change of color occurs in some species in drying. This is distinct from sap stain or colors caused by fungus or bacteria. This is notable in hard maple sapwood and in sugar pine. In the maple, a moist warm atmosphere is conducive to this coloration.

10. Collapse of the cells may occur in some species while the wood is hot and moist. This collapse is distinct from the shrinkage which takes place in the wood substance and is due to a different cause.

These properties of the wood give rise to certain resultant internal stresses which are the main cause of warping, checking, and honey-combing (see Fig. 3). "Washboarding" is due to unequal shrinkage or collapse of adjacent layers of the annual

FIG. 4.



"Washboarding" in an inch board of blue gum (*Eucalyptus globulus*) due to the alternative collapse of the annual rings. This board was perfectly flat when placed in the kiln as is evidenced by the band saw marks running across the surface.

rings of wood and appears on radially sawed lumber (quarter-sawed). (Fig. 4.)

It is chiefly with the analysis of these internal stresses that this article has to do.

### INTERNAL STRESSES AND "CASEHARDENING."

The term "casehardening" is used to describe the condition of wood which contains stresses brought about by drying. It is somewhat ambiguous but commonly used. As the derivation of the word implies, it signifies in general a hardened case on the outside of the wood—derived probably from analogy to the term as used in metal tempering where the outer surface of the iron casting is changed to steel. The analogy, however, is not a very good one and should not be followed too closely.

As applied to wood it is sometimes used to refer to two different, although interrelated conditions. One has to do with the moisture condition alone, and the other with the internal stresses resulting from the hardening of the fibres and the relative shrinkages. In both cases the wood contains internal stresses brought

about by unequal shrinkages and a stiffening of the fibres as the wood dries below its fibre saturation point.

A temporary condition of internal stress may be brought about merely by a difference in moisture content between the inside and the surface, which may entirely disappear when the moisture is equalized provided the fibres have not hardened unequally. Permanent stresses, on the other hand, may result from the unequal moisture distribution whenever the outer and inner fibres become set or hardened at different stages of shrinkage or under different stresses. In such cases the internal stress in the wood remains even after the moisture has been uniformly distributed. This condition is dependent upon the stresses which exist in the fibres at the time they reach their fibre saturation point and begin to harden or receive a " set " as it is termed.

There are four variable factors to consider which affect the result, namely : moisture content of the wood, degree of shrinkage, internal stress, and period at which the fibres become hardened or set. Moreover these factors are partly dependent one upon the other. Temperature is still another factor but may be treated as an independent variable.

When a piece of wet wood dries rapidly, the outer surface necessarily becomes considerably drier than the interior. Under ordinary conditions the outside dries considerably below its fibre saturation point while the interior of the wood is still in a green or wet condition. Normally wood begins to shrink at its fibre saturation point, but inasmuch as the interior of the block of wood has not undergone any shrinkage, the outer fibres are consequently held in what might be considered an abnormally distended condition. Inasmuch as the wood hardens or becomes stronger as soon as it dries below its fibre saturation point, these outer fibres may become hardened in this distended condition to such an extent that if this outer shell were now removed from the block of wood this shell would no longer shrink down to its normal condition. In other words, the outer fibres have thus become hardened or set in such a condition that they will not subsequently shrink the normal amount.

Let us again consider the block of wood in which the interior is still wet and the outer fibres have thus become set in this expanded condition. The outer fibres of the block are then in tension and the inner ones in compression. As the drying now

progresses the inner fibres subsequently begin to dry and will tend to shrink their normal amount. The inner fibres, however, are prevented in turn from shrinking their normal amount by the hardened, expanded condition of the outer case or shell. The result will be a reversal of stresses, the inner fibres now being thrown into a state of tension and the outer into a state of compression. Now, it may occur under certain conditions that the inner fibres will also harden in this somewhat expanded condition and the slight residual shrinkage of the outer fibres may be sufficient so that when the wood has become uniformly dry throughout, all of these stresses will disappear. The casehardening so produced is then of a temporary nature and disappears upon redistribution of the moisture. In the majority of cases, however, where rapid drying takes place, the inner fibres, when they harden up due to drying, remain in a state of tension and the outer fibres remain in a state of compression from the fact that the residual shrinkage of the outer fibres is not sufficient to relieve these stresses. Permanent casehardening therefore results. The question of whether casehardening is temporary or permanent is dependent upon the relative degree of hardening of the outer and inner fibres and the relative amounts of residual shrinkages when they become uniformly dry.

From a consideration of the stresses which occur during rapid drying of a piece of wood, it will be seen that the total shrinkage of the entire block will ordinarily be less in the case of the severely casehardened wood than it will be in the case of a block of wood where normal shrinkage of all of the fibres can take place.

It will also be observed that the first stages of casehardening, in which the outer fibres are in tension and the inner in compression, will tend to produce external checking if these stresses exceed the cohesion of the fibres. Secondly, after the reversal of stresses takes place the result will be that the internal fibres will tend to be pulled apart by the internal tensile stresses provided these exceed the cohesion of the fibres. The outer checks, if they have occurred, will consequently close up due to the compression stresses introduced in the external fibres by the subsequent shrinkage of the internal fibres. This condition of internal checking is commonly called *"honey-combing."*

The analysis of the phenomena of casehardening is rendered complex, on account of interrelation of the four factors mentioned

above—moisture, shrinkage, stresses, and hardening—since all these variables must be considered at the same time. For this reason also the determination of the condition of wood with respect to casehardening is equally complex.

The method commonly used is to cut a thin disk across a stick of wood and slot this disk in the form of a tuning fork, but having, instead of two, a number of prongs. This slotted disk indicates, by the bending of the prongs, the condition of stresses existing at the time of cutting and also the residual shrinkages which may take place during the subsequent drying of the block. For example, let us consider a piece of green wood which is being rapidly dried and suppose the casehardening disk is cut at a period when the outer surface has just dried below its fibre saturation point and the interior is still green, the outer surface being in tension and the inner portion in compression. The prongs of such a disk will bend outwardly when cut on the saw, but when subsequently dried in an oven these prongs will reverse and bend inwardly, due to the fact that the outer fibre has already hardened somewhat in the expanded condition so that its normal shrinkage is less than the normal shrinkage of the inner side of the prongs.

Again suppose that a disk be cut at a period after the reversal of stresses when the outside is in compression and the inside in tension. Such a disk will immediately bend on the saw; that is to say, the outer prongs will tend to bend inwardly. Subsequent drying will only tend to increase the curvature.

It is apparent that there is a period somewhere between these two at which, if a disk be cut, the prongs will neither turn inwardly nor outwardly on the saw, but nevertheless they will subsequently turn inwardly when the disk is dried.

In introducing this subject the assumption was made that the stick of wood was rapidly dried. Ordinarily the more rapid the drying the greater is the casehardening effect. It will be evident that this is brought about entirely by the unequal moisture distribution during the drying of the stick of wood. Were it possible to extract the moisture from the interior of the block at the same rate that it is being extracted from the outer surface, casehardening would not occur either temporary or permanent. Furthermore it will be observed that the more rapid the drying rate, the greater will be the factors producing this condition.

These factors will therefore be reduced to a minimum by the slowest possible method of drying. Consequently, in very slow air drying of lumber, where the lumber is shielded from both winds and dry air, casehardening will be at a minimum, other things being equal. The reason for this is that in very slow air drying the differential in moisture distribution in a block of wood is very nearly equalized. There is not produced the excessive differential in moisture between the interior and the surface which is necessitated by any practicable process of enforced drying.

In kiln drying the aim is to retard the rate of surface drying by a high humidity in the surrounding medium in order to prevent the casehardening from becoming excessive at any time, but some casehardening is inevitable. The condition, however, can be relieved or even entirely reversed as shown in Fig. 8, by subjecting the wood to a high humidity and high temperature (steaming) for a brief time so that the hardened outer fibres are rendered soft and plastic and yield to the stresses.

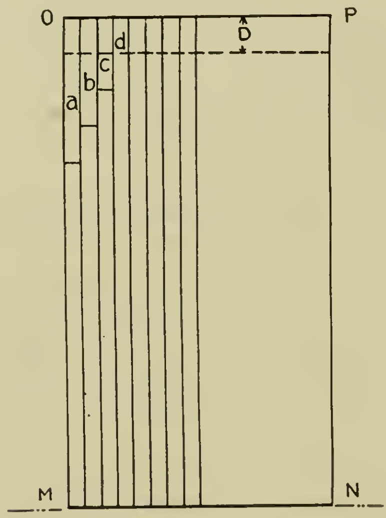
### ANALYSIS OF STRESSES DURING PROGRESS OF DRYING AND OF CASEHARDENING.

In analyzing the internal stresses which occur during the progress of drying a square stick of wood, and the amounts of "setting" and shrinkage which take place, suppose that in Fig. 5, *o p m n* represents a disk cut transversely across the stick so that *mn* is the centre line. Let half the disk be assumed to be cut into 8 narrow strips numbered 1 to 8, strip 8 being next to the centre line of the disk. For convenience of conception, suppose that each strip consists of a spiral spring of equal strength attached to two horizontal bars *mn* and *op,* which are so arranged as to always remain parallel. Let the stresses produced in these springs be directly proportional to the amounts they are stretched or compressed from their neutral position. For the sake of the analogy drying of the wood is to be considered as equivalent to a shortening (not a compression) of the springs. This shortening may readily be accomplished by screwing up a nut on the lower end of each, the ends projecting through holes in the bar *mn.* If the springs are all independent, screwing up the nuts will merely shorten them an equivalent amount, but if they are all fast to the upper bar *op,* and only the outer springs are shortened, these will be stretched or placed in tension, pulling the bar downward and throwing those springs which have not been shortened

into a state of compression. This is exactly what occurs when the outer layers of a block of wood begin to dry below the fibre saturation point.

Notice now that if the springs be shortened one after another until all are finally shortened the same amount, the bar *op* will merely descend the same amount that the springs have been shortened and the stresses will disappear. This is what takes place in a piece of wood when dried without casehardening to a point where the moisture content is uniformly the same in each layer. This may be considered as *normal shrinkage* and is prob-

FIG. 5.




ably directly proportioned to the amount of hygroscopic moisture removed. Rarely if ever is this condition realized in drying anything but very thin material.

What generally happens is that the outer layer tends to shrink in drying but is considerably stretched by the resistance of the inner layers. Being a somewhat plastic material, it soon hardens in the stretched condition, so that it no longer tends to shrink the normal amount. Upon complete drying the inner layers will tend to shrink their normal amount, but will be slightly stretched (less so than was the outer layer), thus throwing the outer layer into compression and the inner layers into tension; they will also harden in their slightly stretched condition, but the stresses,

although less than they were at the first stages of drying, may remain in the wood. The wood is then permanently casehardened.

Going back to the analogy of the springs. When the outer spring has been shortened, say half the amount which would correspond to normal shrinkage, suppose it be annealed and rehardened, so that without altering its present stress, it then requires a greater force to stretch or compress it the same amount as before, and that approximately one-half of the total amount which it formerly might have been shortened (normal shrinkage) has already been removed. As the inner springs are then shortened in turn the outer "set" spring is thrown into compression and behaves very much as it would if it had been adjusted back again to its original length (as though it were resoaked in the case of wood), although this outer layer continues to be in a drier state than the inner layers. As a matter of fact the outer layer of wood not only acts as though starting again at its original length, but it has also become greatly stiffened at the same time. Here, however, the analysis becomes too complicated to follow clearly, and we will therefore disregard for the present the increase in stiffness which takes place in the drying of the various layers, and assume the springs to remain the same strength.

Having attempted to illustrate the behavior of the wood by the hypothetical analogy of the springs, let us follow the line of reasoning a few steps farther. For convenience of reference, let us assume each spring to be 100 inches long. Suppose the nut on No. 1 be screwed up 8 inches, it will be thrown into a state of tension which will accordingly bring the other seven springs into a state of compression. The whole bar *op* will then evidently be lowered one inch, thus compressing the seven springs each 1 inch and stretching No. 1 a total amount of 7 inches. This is what happens when the outer layer of a piece of wood dries below its fibre saturation point, while the interior still retains some free moisture. Now suppose that No. 1 becomes "set" in its shortened but expanded condition, that is to say, in this position it no longer exerts the tensile pull which it exerted before, but its stress is neutral at the 1 inch shortened position. The bar *op* will therefore rise sufficiently to bring about a balance of stresses and this will cause a new tension in No. 1 and new amount of compression in the rest; No. 1 is then neutral at 99 inches and not at 92 inches as when first shortened. In other words, the effect

of shortening it the 8 inches has been done away with and it now acts the same (disregarding its increased stiffness) as though it had originally been shortened by one inch. If detached from the bar it will remain 99 inches in length, and when the disk is completely dried (all springs shortened 21 inches), it cannot be shortened its normal amount, as the others will be. Assuming the normal shrinkage (total possible shortening of the bars) to be 21 inches, No. 1 having already been shortened 8 inches and being neutral at 99 inches, it can therefore be shortened only $(.99 \times 13) = 12.87$ inches. So in the final state, the seven springs will be 79 inches long and No. 1 will be $(99 - 12.87) = 86.13$ inches. (The total possible shortening of all springs from their original lengths having been assumed as 21 inches.)

In this way we may analyze the progressive conditions of the stresses in the eight springs and their corresponding shortenings, corresponding to the progress of drying of the wood from the outer surface inward and the successive casehardening of the outer layers, when first separated from the bars, and when finally shortened the complete amount representing a state of complete dryness after separation. To make this system of analysis clearer, let us follow a single case for an example. Let springs 1, 2, 3, 4 each be shortened respective amounts *a, b, c, d,* by screwing up nuts on their bottom ends, and let the rest remain the original length of 100 inches. Let $D$ be the distance the bar *op* will descend (equals the shrinkage of the entire disk as a whole). Let $n$ be a factor by which if the distance the spring is shortened be multiplied it will give the stress existing in that spring, and let negative signs indicate tension and plus signs compression. Then the following equation will represent the stresses in all of the springs:

$$(D-a)n + (D-b)n + (D-c)n + (D-d)n + 4(D-O) = O \quad (1)$$

Since the summation of all these stresses must equal zero

$$8D = a + b + c + d$$

Now we are at liberty to shorten each spring an assumed amount (corresponding to the degree of drying out of the successive layers). For instance, suppose

$$d = D,\ a = 3c,\ b = 2c$$

then the relationship of $D$ and $c$ may be calculated.

Substituting in the equation (1):

$$7D = 63, \ c = \frac{7}{6} D$$

Suppose $D = 6$ inches then

$c = 7$, $b = 14$ and $a = 21$ inches, and the stresses are No. 1 $= 15n$ No. 2 $= -8n$, No. 3 $= -1n$, No. 4 $= 0$ and each of the others $= +6n$.

Spring No. 4 having been shortened (shrunken) the same amount as the bar is lowered will neither be compressed nor elongated and will have no stress.

Suppose now that spring No. 1 be extended to its original length by unscrewing the nut on the bottom the full amount (swelling to its original condition by wetting in cold water or saturated air). The others remain shortened the same amounts as before.

Let $D_1$ be the new position assumed by the bar

$$8D_1 = 0 + 2c + c + d. \quad 8D_1 = 3c + D = 21 + 6 = 27. \quad D_1 = 3\ 3/8$$

| No. 1 | No. 2 | No. 3 | No. 4 | Nos. 5, 6,7,8 |
|---|---|---|---|---|
| $+3\ 3/8n$ | $-10\ 5/8n$ | $-3\ 5/8n$ | $-2\ 5/8n$ | $+4(3\ 3/8)n = 0$ |

The stress in No. 1 has changed to compression, and the tension in Nos. 2 and 3 has been increased and No. 4 has now been placed in tension.

Without following further the calculations in detail, the various relative stresses and the total shrinkages of the disk are set forth in Table I for several assumed progressive conditions of casehardening and reabsorption (neglecting the increased stiffening of the springs, as explained before).

The first column after " Conditions " gives the shrinkage of the disk as a whole in inches (a wholly conventional unit assumed for convenience of discussion) and the next eight columns show the relative stresses in each of the respective strips. They represent the actual stresses existing in the disk at the horizontal centre line *mn*. (In the unslotted disk the stresses decrease as the ends are approached, becoming zero at the end, due to the shearing stresses between the adjacent strips.)

A careful study of Table I will reveal many interesting facts and will explain the peculiar and apparently anomalous behavior of the prongs of the test disk when slotted at different periods of the drying and when cut into different thicknesses.

The progress of the stresses in the eight layers from the outer surface to the centre of the stick of wood during drying may be

TABLE I.

*Stress Conditions During Progress of Casehardening.*

| Condition of Casehardening | Shrinkage of Disk, inches | Comparative Stress in Terms of Some Constant *n* Strip No. 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| *A*. Strips 1 to 4 have dried, 5 to 8 still wet, equivalent to shortening *a*, 21; *b*, 14; *c*, 7; *d–D* inches. | 6″ | −15 | −8 | −1 | 0 | +6 | +6 | +6 | +6 | Strip 4 is neither in tension nor compression. |
| *B*. Strip No. 1 is swelled to full length, others not altered. | $+3\frac{3}{8}$″ | $+3\frac{3}{8}$ | $-10\frac{5}{8}$ | $-3\frac{5}{8}$ | $-2\frac{5}{8}$ | $+3\frac{3}{8}$ | $+3\frac{3}{8}$ | $+3\frac{3}{8}$ | $+3\frac{3}{8}$ | Tension in 2, 3, 4 is increased but not as great as No. 1 in *A*. Compression in 5, 6, 7, 8, all decreased. |
| *C*. Strips No. 1 and No. 2 swelled to full length, others unaltered. | $+1\frac{5}{8}$″ | $+1\frac{5}{8}$ | $+1\frac{5}{8}$ | $-5\frac{3}{8}$ | $-4\frac{3}{8}$ | $+1\frac{5}{8}$ | $+1\frac{5}{8}$ | $+1\frac{5}{8}$ | $+1\frac{5}{8}$ | Tension of No. 3 increased but not as great as in *A*. |
| *D*. Strips Nos. 1, 2, and 3, swelled to full length, others unaltered. | $\frac{3}{4}$″ | $+\frac{3}{4}$ | $+\frac{3}{4}$ | $+\frac{3}{4}$ | $-5\frac{1}{4}$ | $+\frac{3}{4}$ | $+\frac{3}{4}$ | $+\frac{3}{4}$ | $+\frac{3}{4}$ | Strip 4 now carries the only tension. |
| *E*. Condition *A* resumed. No. 1 is then softened by steam so it offers no compression as it does in *B*. | $+3\frac{1}{2}$ | 0 | $-10\frac{1}{2}$ | $-3\frac{1}{2}$ | $-2\frac{1}{2}$ | $-3\frac{1}{2}$ | $-3\frac{1}{2}$ | $-3\frac{1}{2}$ | $-3\frac{1}{2}$ | Strips No. 2, 3, 4 are greatly increased in tension by this steaming. |
| *F*. No. 1 becomes "*set*" at the condition in *A* so that its normal length is now 6″ shorter than at first. All the others are shortened progressively, amounts No. 2, 21; No. 3, 19; No. 4, 17; No. 5, 15; No. 6, 13; No. 7, 11; No. 8, 10 inches. | +14″ | +8 | −7 | −5 | −3 | −1 | +1 | +3 | +4 | This is the first evidence of true casehardening. After slotting and completely dried all the other strips will shrink 21″. No. 1 remaining at 6″ since it has previously been dried its full amount. See Case *A*. |

TABLE I—*Continued*

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *G*. Strips No. 1, 2, 3 become set in *A* equivalent to starting each with a normal length 6″ shorter than originally. | $+10\frac{1}{2}''$ | $+4\frac{1}{2}$ | $+4\frac{1}{2}$ | $+4\frac{1}{2}$ | $-6-\frac{1}{2}$ | $-1\frac{1}{2}$ | $-2\frac{1}{2}$ | $-\frac{1}{2}$ | $+\frac{1}{2}$ | Second case in casehardening. When dried Nos. 4 to 8 shrink 21″ No. 1 remains 94 inches long since it shrinks no further being dry. No. 2 shrinks 6″ + (21 − 14) X.94″; No. 3, 6″ + (21 − 7) X.94″. |
| *H*. Strips 1, 2, 3 have become "set" but No. 1 in Case *A* with a shortening 6″ and 2 and 3 in Case F with a shortening of 14″. All the rest are assumed to be completely dry equivalent to shortening each one 21″. | $+17\frac{3}{8}''$ | $+11\frac{3}{8}$ | $+3\frac{3}{8}$ | $+3\frac{3}{8}$ | $-3\frac{5}{8}$ | $-3\frac{5}{8}$ | $-3\frac{5}{8}$ | $-3\frac{5}{8}$ | $-3\frac{5}{8}$ | This represents the ultimate condition when uniformly dry. Note that total shrinkage of disk is only $17-\frac{3}{8}''$ instead of 21″. |
| | The final shrinkage when completely dry will be as follows: | | | | | | | | | |
| | | 6″ | 14″ | 14″ + | 21″ | 21″ | 21″ | 21″ | 21″ | |
| *I*. Same as *H*, but strip No. 1 is then softened by steaming so as to remove all stress. | $+19''$ | 0 | $+5$ | $(21-19)$ $+\frac{86''}{100}$ $+5$ | $-2$ | $-2$ | $-2$ | $-2$ | $-2$ | Note the increased total shrinkage of disk. |
| *J*. Same as *I* but after steaming No. 1 shrinks its normal amount of 21″ the same as if it had not become casehardened. | $19\frac{1}{4}''$ | $-1\frac{3}{4}$ | $+5\frac{1}{4}$ | $+5\frac{1}{4}$ | $-1\frac{3}{4}$ | $-1\frac{3}{4}$ | $-1\frac{3}{4}$ | $-1\frac{3}{4}$ | $-1\frac{3}{4}$ | This explains final reversal of casehardening. If slotted between No. 4 and No. 5 the prong will remain straight. |

graphically indicated as in Figs. 6 and 7, in which tension is shown by distances below the horizontal lines and compression by distances above. This also shows relatively the lengths which the strips will assume if the disk be slotted at the condition under consideration. In the diagrams the combined area above the horizontal line always equals the area below.

Let us consider what happens in a few cases illustrated in Figs. 6 and 7.

If a disk be cut and slotted in Case A, the outer prongs will at once bend out on the saw, although no casehardening has yet occurred. If then dried slowly the prongs will become parallel again and of the same length.

In the Case B the outer prong will have a slight tendency to bend in on the saw, but if the disk be given a single cut through the centre the two prongs will bend outwardly on the saw. When subsequently dried, however, in both cases the prongs will bend inward. In Case F the same is true to a greater degree. In Case G, however, the prongs cut anywhere after the third strip will at once bind on the saw and will still further bind when finally dried. In Case H, if slotted up at any point, the outer prongs will at once bind on the saw, and remain so. The inner prongs 5 to 8, however, will remain straight.

If Case A be steamed at a low temperature or placed in cool, damp air, the outer portion will swell and offer a compression effort which will have the effect at first of increasing the tension on the inner layers, which is a bad effect as it tends to develop internal checking or cause external checks to run in deeper. Successive stages are shown in Cases B, C and D. Since the outer layer is not softened at the cool temperature, it will not intercrush (or crunch) under compression, and therefore no advantage is gained, since the same tendency to caseharden is again set up when it is dried again. If it be steamed, however, at a sufficiently high temperature to render it plastic, the outer layer will intercrush slightly as shown in Case E, and when further drying of the stick is resumed, it will not offer so great a resistance as it would formerly, as in Case H. Casehardening has thus been slightly reduced.

The most salubrious effect of steaming, however, is obtained after the Case F has been reached, and this reaches its maximum in the Case H. The effect of high temperature steaming is here

FIG. 6.

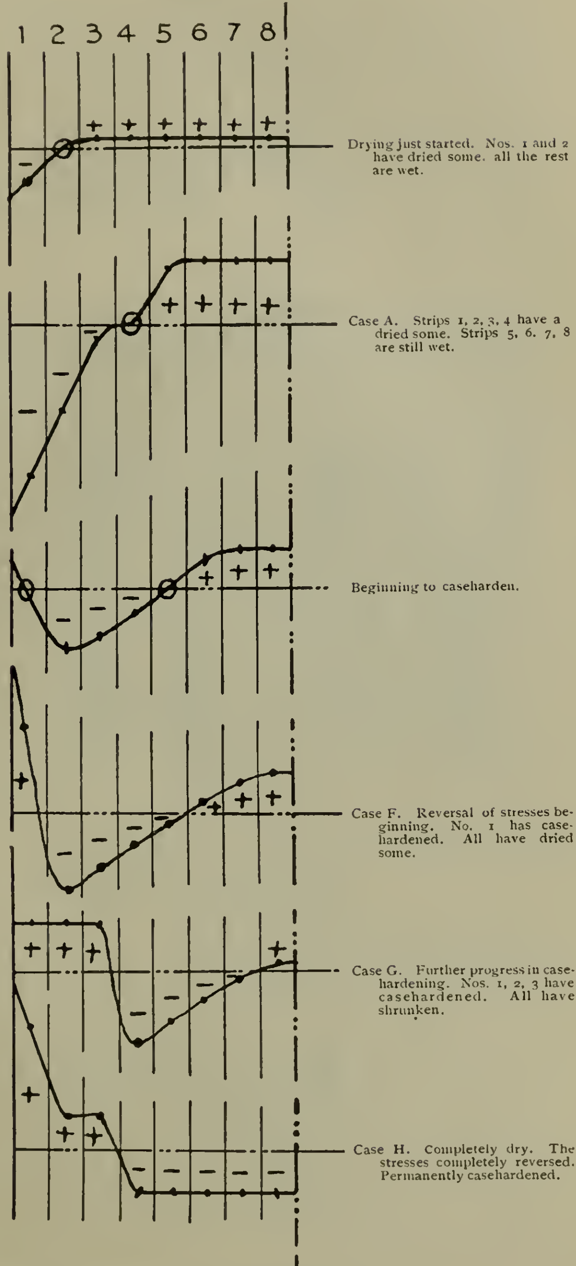



Diagram showing stresses in wood while drying.

FIG. 7.

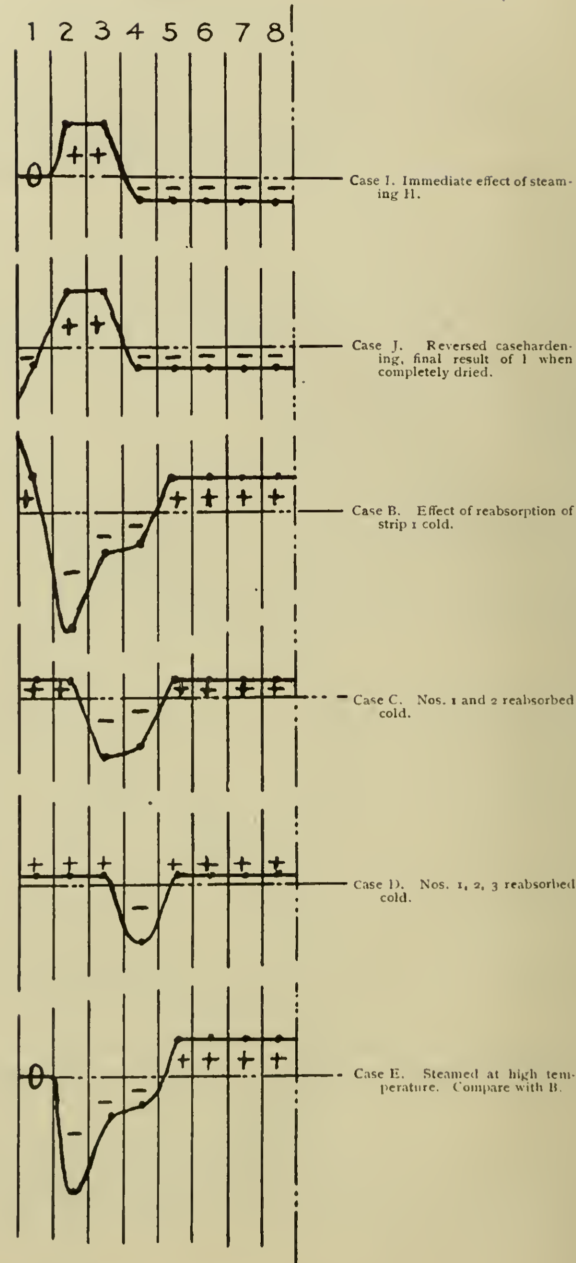



Diagram showing stresses in wood while drying.
(Continued from Figure 6.)

to completely eliminate the compression stress in the layers affected, as is illustrated in the single Case I. The ultimate result, however, provided the effect has not penetrated to all layers under compression stresses, will inevitably be a reversal of casehardening, shown in Case J. In this case, if the disk be slotted between 2 and 3, the outer prong will turn out slightly on the saw in Case I, and much more so in Case J. On the other hand, the next prong, consisting of strips Nos. 3 and 4, will still turn

FIG. 8.


Discs cut from casehardened maple and oak boards. The alternate ones on the left show the condition of the boards when first dried; those on the right show reversal of stresses brought about by steaming the same boards at a slight pressure.

inward, the same as in Case H. If sawed in the middle, however, there is much less cupping in J than in H; in fact, it might easily be that the stresses are balanced so there would be no cupping at all of the half-disk.

If the effect of the steaming be sufficient to penetrate all the layers under compression, all stress may be removed thereby.

While the cases chosen for illustration are largely empirical, and actual conditions will vary therefrom not only in relative intensities but in distribution, it seems probable that the maximum total stresses are very apt to occur in the first stages of drying as in Case A. The tension inside the block is at no time as

intense as on the surface. It may be that honey-combing starts initially with a small surface crack, which then follows inwardly as the wave of tension moves to the centre, somewhat in the manner that a crack in a pane of glass will follow the progress of a comparatively slight stress, much less than that which would be necessary to initiate the crack in the unbroken piece. If this is the case, cold reabsorption or steaming at a low temperature, before true casehardening has taken place to a considerable extent, is of no advantage but positively detrimental, as such treatment is here shown to intensify the tension in the adjacent layers progressively. High temperature steaming, on the other hand (Case E), may be beneficial in relieving the ultimate casehardening (external compression effect) at the stage indicated in Case A, and it is certainly beneficial after decided casehardening has taken place at Cases F and H.

For aeroplanes, unequal moisture distribution, which means temporary stresses, is undesirable for any purpose. Permanent casehardening, such as illustrated in Case H, is not of itself very serious for wingbeams and small parts provided it is not severe; it may, however, presage an improper drying treatment which would be ground for rejection of the material. For propellers, however, any appreciable casehardening is detrimental as the internal residual stresses may cause changes to take place in the shape of the finished parts. Moreover, these stresses may change with time, which may introduce unknown stresses in the blades or tend to shear the glue joints. Or they may even cause checking or internal cracking to take place at some future time.

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**Shock-proof Tungsten Lamp.** ANON. (*Scientific American*, vol. cxx, No. 25, p. 649, June 21, 1919.)—Despite the many improvements introduced in the manufacture of tungsten lamps, they have remained delicate until the present. There was a time, of course, when tungsten lamps had to be handled with extreme care to avoid jarring and shattering the delicate filament; but in more recent times the tungsten lamps have come to be fairly rugged and available for almost all purposes save in mills, printing plants, and other places subject to intense pounding or shocks. It has remained for one of our leading electric lamp manufacturers to introduce a new type of tungsten lamp which incorporates a shock-absorbing feature. The filament mounting, instead of forming an integral part of the glass stem as is usually the case, is spring-supported. This feature makes this lamp serviceable and preferable under almost all conditions where carbon lamps have been used heretofore.

# INDUSTRIAL LIGHTING.*

BY

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If every working man in the industries of this country lost one minute per eight-hour day, each day, due to inadequate working facilities, the economic loss to the country, based on certain statistics, might approximately be set down as equal to $10,000,000 per annum. Similarly, a loss of one hour per day by the total employees in all industries would mean roughly a loss well on toward a half billion dollars per annum. These figures are based on the estimated wages in this country per annum as reduced to the total wages per minute or per hour, these factors then being employed as a basis for the determination of the losses just mentioned.

Reference will be made later to losses due to poor light and, conversely, to gains made possible by highly adequate light, and when the loss of a minute or an hour per day due to poor light is mentioned, while it may seem trivial in itself, its importance to the industrial economy of the country will be more evident from the foregoing general figures, while its relatively large magnitude when compared to the costs of the best lighting will appear subsequently.

### DEVELOPMENTS IN GAS AND ELECTRIC LIGHTING CONTRASTED.

Those who have followed the developments in electric and gas lighting during the past years have probably been impressed by the apparent rivalry between the manufacturers of gas and electric lamps and appliances. This rivalry may, it is true, be only apparent, but it is interesting as throwing into relief some of the possible influences back of the rapid developments in these two fields. Gas lighting, as the older of the two, was employed in about the same way in the form of the old fish-tail burners for a number of years with little or no attention to reflectors or the scientific distribution of the light. Later, the

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* Presented at a joint meeting of the Section of Physics and Chemistry and the Philadelphia Section, Illuminating Engineering Society, held Thursday, February 6, 1919.

electric lamp appeared and the many developments in electric lamp efficiency and in the effective use of the light from such sources, has been paralleled by similar developments in gas lamps and in auxiliaries for the highly efficient utilization of the light from these sources.

In somewhat the same manner the developments in the means for securing light in factory buildings has witnessed a contrast between natural and artificial illumination. There may or may not have been an actual rivalry between building constructors, on the one hand, in the design of windows and monitors for admitting daylight, and those who have been responsible for effective artificial lighting on the other hand, but the past ten to fifteen years have witnessed marked advances in both of these fields. Not only has there been an awakening to the needs of the case but new methods and new types of artificial lighting equipment have been applied to industrial buildings in recent years and along with them has come a higher appreciation for buildings so designed as to admit plenty of daylight and in such directions as to reach the working surfaces effectively. In what follows, it is the intention to dwell to some extent on both of these phases of industrial lighting, partly by way of pointing to individual characteristics of the illumination from both natural and artificial sources, and to some extent in contrasting the two.

### SOME CAUSES FOR POOR LIGHTING IN EARLIER PRACTICE.

It might seem at a first glance that the importance of the best form of illumination for industrial processes is so fundamental and obvious that there would be little or no need to emphasize the relations of good lighting to effective and accurate workmanship. The widespread neglect of such facilities indicates, however, that lighting is one of those things in the factory equipment which can readily be overlooked and concerning which there is still much ignorance on the part of industrial managers and shop owners. These conditions make it necessary to dwell repeatedly upon such things as the value of good light to production, and also upon the physical means now available for the accomplishment of successful illumination at the working surfaces in the industries.

Going back fifteen to twenty years, the inadequate illumination in many older industries may easily have been the result not

so much of neglect, as of an inability to secure suitable lamps. The older arc lamps, representative of the larger sizes, and the carbon filament lamps, of the smaller sizes, each had their own limitations for the attainment of success in factory lighting. Large lamps were not adapted to low ceilings and the apparent difficulties in the way of providing general and uniform illumination over the entire floor areas where high ceilings existed, either with arc lamps or with groups of small carbon filament lamps, often made localized lighting the logical result in earlier practice. Intermediate ceilings, falling between low and high clearances, constituted an unusually large proportion of some factory areas, and such locations, in earlier practice, sometimes presented greater difficulties from the viewpoint of general illumination, than either the low or the high spaces.

The successful use of tungsten and of mercury vapor lamps for factory lighting purposes marked a new era in this field of artificial illumination and solved many problems which previously had been difficult to handle with the very limited lamp sizes in the arc and the carbon filament types. In fact, the very obvious advantages of a lamp of medium size, whether tungsten or mercury vapor, are so great in the successful illumination of many factory spaces, that it is an open question whether the recent development of nitrogen-filled lamps with very high efficiencies in the large lamp sizes is an advance equal to the appearance some fifteen years ago of the older tungsten lamps in medium sizes, at least so far as the industrial lighting field is concerned. In other words, it may be found desirable to illuminate many factory interiors with less efficient tungsten lamps of the intermediate sizes so as to secure better distribution of the light through the larger number of units thus required than to adopt the larger lamp sizes merely to obtain a unit with a higher candle-power per watt rating.

### REASONS FOR DEVELOPMENTS IN FACTORY LIGHTING PRACTICE.

In spite of the widespread neglect of the ideas of good lighting in many industries, there has been a notable development in the way of better lighting among the plants of the more progressive class during the immediate past. This development may be ascribed to the newer types of lamps and to more carefully designed reflectors, with the possibilities for the highly effective

lighting results they have made available, but other factors have doubtless contributed to this development. One of these perhaps has been the ideas back of scientific management and the higher appreciation which these ideas have emphasized for a favorable working environment for employees. The advantages of good working facilities, of which lighting is a type, have come to be looked upon in recent years as tangible and very real factors in the successful management of American industries, and additional attention has been directed toward this phase of the subject by the stress of the recent war emergency, which will be referred to again later on.

Another influence which has undoubtedly been back of these developments in factory lighting is the keen interest which has been taken in the subject by lamp and reflector manufacturers. Aside from any commercial considerations, this active and painstaking work by the manufacturers has been such as to merit the approval of all of us who view the problem from just as interested although a less commercial point of view. The need for continuously keeping these high ideals in mind on the part of the lamp and reflector manufacturers is, however, increasingly great because of the effect upon any industry of the law of supply and demand. People generally to-day confuse good lighting with extremes in glare and brilliancy from high candle-power lamps. For reflector and fixture manufacturers to give way to this popular prejudice favoring brilliancy of lighting units would be a step backward, and it is to be hoped that light users may in time be educated up to that point where they will appreciate good illumination and the freedom from glare in such a measure as to supply the necessary commercial demand for equipment which meets these primary requirements in good lighting practice. It is hardly necessary to add that the industrial field is one of the important cases where these comments apply very generally.

Finally, as a fourth cause for the increasing attention to better lighting in recent years, there may be mentioned the slowly growing emphasis which is being placed upon the subject by state labor departments through codes and other legislative enactments covering industrial lighting. These state regulations, although drafted primarily with the view of safeguarding employees through better lighting, and hence not directing attention to any extent to the economic advantages of good light, except perhaps

indirectly, have undoubtedly become quite a potential factor in this field. Some of the developments in state codes will be referred to later.

### RULE OF THUMB VERSUS EXPERT METHODS.

To the popular mind, the duties of the industrial lighting engineer probably consist merely in the choice of lamps and in hanging these lamps at certain locations. In fact, the actual conduct of industrial lighting design, or planning, as it might more properly be termed, by many architects and others, depends to such an extent upon rule of thumb methods, that such a conclusion may be valid when referred to such methods. The design of a truly successful factory lighting system, however, often presents peculiarities and special problems which merit individual attention not only to given sections of the plant from the standpoint of the kinds of work conducted, but sometimes to the particular needs of individual workmen. Hence, it is apparent that the whole subject can either be looked upon, on the one hand, as one susceptible to solutions by rule of thumb methods, or, on the other hand, as one in which highly specialized talent can well be utilized by the plant management.

To my own mind, the latter method is the best if not the only safe course to follow. Eyesight is too valuable an asset to the millions of wage earners of this country, and also to the economic interests of industry, to neglect the light under which vision must function in seeing such an infinitely wide variety of industrial operations, where the personal element combines, under both physiological and psychological influences, to still further complicate the problem. Therefore, merely from the standpoint of providing illumination which is correct both in quality and quantity, expert assistance is warranted in the making of such plans. Moreover, there is a wider aspect of the matter, and to give a general idea of the variety of additional problems which the industrial illuminating engineer may be called upon to handle, it may be in place to enumerate very briefly several items which have constituted a part of his duties under actual working conditions.

### ITEMS CLOSELY ALLIED TO INDUSTRIAL LIGHTING.

These include such things as the study of distribution circuits and transformer capacities for the supply of constant voltage to the factory lamps, the study of the proportion of motor load to lighting load on given circuits, in its relation to voltage variations

on the lighting part of such combined loads, and the factors involved in the possible subsequent recommendation that such combined loads on a given circuit be separated. Again, in one factory I recall steps that were taken to establish the minimum voltages to apply to given rated lamps for the maintenance of approximately white light. Other important items have been the establishment of proper lamp arrangements and suitable intensities for each class of work and for each location, such as the office, the drafting room, the foundry and the machine shop. Maintenance work must be standardized, since no industrial lighting system can be expected to keep up to its original excellence unless lamps and reflectors are cleaned, and burned out lamps are renewed regularly and promptly.

Many other problems may present themselves, such as the prevention or, at least, the reduction of theft of lamps in the large factory; campaigns among the superintendents and the employees looking towards the intelligent economy of light; the prevention of polarity reversal on direct current circuits, where such a reversal may cause instant injury to given types of lamps; the large question of voltage drop in the distributing circuits, which may sometimes include the factor of mutual inductance where lamps are supplied from two phase alternating current power mains. Then there is the important point of the most economical method for producing a given quantity of illumination at the working surfaces, which includes such factors as light walls and ceilings; also the selection of those types of reflectors, whether glass or metal, most suitable for factory conditions, and at the same time capable of increasing the proportion of the total light from the lamps which reaches the working surfaces; the study of the effects of good light upon rates of production and upon accuracy of workmanship; the methods of wiring best suited to the various types of factory building construction; the best ways to provide light for stairways and passageways and the relations of such light to accident prevention; the very special study of particular cases and operations where unusual requirements are imposed upon vision; the relative advantages of clear and of translucent glass for factory windows from the illumination standpoint; color effects upon various kinds of material, important in textile establishments and sometimes in such special cases as the assortment of metals like copper, brass and iron with their characteristic differences in color.

RESPONSIBILITY OF THE SHOP ELECTRICAL DEPARTMENT.

Problems of peculiar interests, and sometimes correspondingly difficult, arise from time to time in such work, and among these is that of the proper illumination of the instruments on the switchboards of the shop power-house, or the faces of time-clocks located overhead in the aisles of some factories, the illumination of boiler-room gauges, and of coal bunkers, and that fundamental problem of providing enough of a side component in the resulting illumination properly to light vertical or side surfaces of the work.

It is readily recognized that many of the foregoing items which may confront the industrial lighting engineer have received sufficient attention during the past few years to have become in a way standardized. Furthermore, some of the things mentioned may, in certain cases, fall under the jurisdiction of other departments of the plant. The list is given, however, to show that industrial lighting constitutes a problem of fairly broad possibilities, and that it touches a variety of the items which go to make up the shop equipment. Perhaps the close alliance of shop lighting with so many divisions of the factory equipment may be one of the reasons why it is neglected or overlooked, through the assignment of the lighting problem to the care of a factory foreman or superintendent in charge of the electrical department or possibly of the power-house and distributing circuits as well as the motors and general power conditions, with so many interests that there is little time available for specialized study of the lighting conditions and their effect upon vision and upon production. However, there is this compensation even where such conditions exist, that the shop man directly concerned with the supervision of the lighting, although often entirely incapable at the outset, through ignorance of the principles involved, of successfully handling the problem, will often be found most receptive when suggestions are made and often develops an aptitude for the work which enables him to handle it very effectively.

THE PERSONAL EQUATION AMONG EMPLOYEES.

The matter of supplying light for the employees of an industry is thus complicated by the infinite variety of operations and the kinds of things pertaining to the work handled in the various classes of establishments, which make it utterly impossible to assign rules, for the simple reason that while they may perhaps

be adaptable to one kind of work, they may at the same time be entirely inadequate for another. Moreover, the illumination of a piece of work is not only a matter of furnishing so and so many units of illumination intensity upon that work, but its effect in rendering the work visible will be governed very largely by physiological and psychological characteristics of the workman himself. It is not surprising, therefore, to find a person dissatisfied with an ideal lighting system, not because of any difficulties in seeing the objects illuminated, but because the lamps "are too high," or "the quality of the light is too cold," or "the bowls of the lighting fixture are too dim."

On the very face of it, therefore, where light must be furnished to many employees in large office or shop sections, it is almost fundamental to the successful handling of the problem first, to know what is the right and proper method to adopt and then to adhere to this in spite of criticism on the part of employees until such time as the system has been given a fair trial, and individual rather than collective comments can be sifted out. When this time arrives, say after a month of trial for the new system, then individual complaints can well be investigated and, where necessary, remedied.

In this connection, I have seen large factory sections where individual lamps were depended upon solely for the light, and where a new system of general illumination with overhead lamps was about to be installed, when the foremen and superintendents foresaw a distinct need for the retention of the local lamps close to the work. A general complaint in advance of the new installation was forestalled by the simple expedient of agreeing to remove all drop lamps at the time the new system went into effect under the condition that those drop lamps which might be called for after, say a six weeks' trial of the new system, would be reinstalled if found actually necessary. The success of such an expedient can be very gratifying to those responsible for the new system, if the new system is really a superior one, but the designing engineer should never be so sure of himself as to neglect proper attention to individual complaints, which are often entirely justified by special circumstances. It is a cause for regret that there is a notable tendency to turn down such complaints after a new system is installed which the proprietors consider first-class, and I have run across cases of this kind where such a policy

worked a real hardship upon certain employees, for whose work the new system did not meet the needs for good vision.

### PHYSICAL ASPECTS OF THE PROBLEM.

To these subtle physiological and psychological factors there must be added the physical part of the problem, which is concerned with such things as the surroundings of the location to be lighted, the class of things to be seen, the intensities of illumination to provide, and the types of lamps and of reflectors to use and their suitable arrangement. To take all of these factors into account obviously calls for the assistance of specialists in a number of fields, and, conversely, thus indicates why those interested in illumination constitute such an exceedingly wide variety of professions. The personnel of the membership of the Illuminating Engineering Society is a reflection of this interesting feature, and the presence in its membership lists of physicians, ophthalmologists and psychologists, as well as of physicists and engineers, is an index to the ramifications of the field.

Turning now, however, to some of the effects of surroundings and of working conditions generally upon the industries as a whole, we find, first, that light holds an important place in what may be termed the factors which determine the character of the shop environment; and second, that light, as one of the factors, is closely related to the employee through its effect on his ability to see clearly, and thus, in turn, to the production rate, to the amount of defective workmanship, and to the likelihood of accidents.

### INDUSTRIAL LIGHTING AND THE WAR INDUSTRIES.

This close relationship between good and bad light, as the case may be, and the welfare of the employee, together with what has seemed for years to be a more or less close relationship between good light and normally rapid production, between good light and better workmanship, and between good light and a low accident rate, may be taken as an indication of why the question of highly adequate light for the industries was looked upon during the recent war as an item of fundamental importance to war work. In fact, one of the departments of the War Industries Board, known as the Employment Management Division, committed itself during the past year, prior to the signing of the armistice, to the preparation of instruction courses, for employment managers

throughout the country, which contained plans for advancing the ideas of such men, by intensive instruction, in the relations of just such factors to the employee, to production and to the accident rate.

This is a significant point. To aid the industries under the pressure of a war emergency, natural and artificial lighting were considered an important part of an intensive war program. The campaign to gather information for these purposes last year forms an interesting commentary upon the necessities and urgency of work under the pressure of war needs. It was my own privilege to gather a large amount of data for the Employment Management Division of the War Industries Board, at its suggestion and by its authority, on natural and artificial lighting last year before the close of the war, and the cessation of hostilities has led this Division to place at my disposal practically all of the files of data and other information thus accumulated, so that I am privileged in a part of what follows to comment on certain interesting points and on some conclusions based on the information gathered during the past year as a part of the war program.[1]

### RELATIONS OF GOOD LIGHT TO PRODUCTION.

The exact relations of good light to industrial management are important for several reasons. First, and perhaps foremost, is the necessity of convincing the factory manager that the expenditure for a highly adequate system is warranted by the effects it is likely to have upon the management of his employees; and second, in the assurance which such relations give to the industrial lighting engineer or salesman that his efforts to raise the standards of factory lighting are warranted by the results. These relations of good light to management have been expressed in a variety of ways on a basis of the more or less obvious effects it is likely to have on increased production for the same labor cost in a plant, in the greater accuracy of the workmanship in the well-lighted shop, in the reduced accident hazard, in the avoidance or the minimizing of eye strain, and the healthy reaction upon the working force due to the more cheerful surroundings and the more comfortable conditions afforded by the light *versus* the gloomy interior. Adequate general illumination also removes

[1] The Employment Management Division of the War Industries Board now forms a part of the Federal Board for Vocational Education.

dark corners, and it is commonly observed that such a shop is likely to be kept cleaner than companion spaces which are relatively dark. Greater attention to janitor service promotes neatness on the part of the employees and thus tends to raise the tone of the plant.

These advantages of good light are all valuable as showing its importance to any plant and they have often formed the basis for decisions to install better lighting in places formerly very poorly illuminated. However, to say that good light promotes production and reduces accidents is a qualitative statement. The average shop manager is receptive to such ideas; but, in themselves, such abstract statements are difficult to translate into actual returns for the expenditure involved and hence lack the definite characteristics which would so often convince the manager that his judgment concerning the need of a new lighting system is correct.

### ANALYSIS OF LIGHTING COSTS.

One of the first steps towards a more definite basis for setting forth the advantages of good shop lighting was the now well-known type of analysis suggested by Chas. F. Scott in an editorial in the *Electric Journal* in May, 1910, in which he emphasizes a new viewpoint in the consideration of industrial lighting, by suggesting that the cost per day for the best lighting system in a given factory section may conveniently be evaluated to the equivalent wages per day in that same section. At a first glance it does not appear just what such an evaluation may amount to, but since Professor Scott's suggestions in 1910, this relationship has commonly been found to be on the order of two to six minutes. In other words, the entire cost for lighting a shop section per day will usually be found to be the equivalent of the wages in that section for several minutes of the entire working day.

The foregoing figure has often proved to be most conclusive in the survey of an old system and one which has been entirely inadequate, because of the relative ease with which time losses due to inadequate light may be observed by inspection of the shop and by inquiries of the foremen and others in charge. Any shop section, therefore, in which time losses of, say a half an hour per day, occur because of poor light, should obviously reap quite a reward by the adoption of a new and improved system at a cost for operation of one-sixth of the daily loss in wages due to the old system.

EXPERT OPINIONS ON THE LIGHTING NEEDS OF THE INDUSTRIES.

This form of analysis, coupled with personal investigations in the field, have long been used as the basis for the commonly accepted idea that good lighting aids factory production, and that the average lighting conditions in the industries could well be raised to standards considerably in excess of present values. In fact, during the past year, that is to say, before the close of the war, a canvass was made among leading illumination experts in this country [2] to ascertain by how much industrial lighting ought to have been adjusted or changed from standards existing before the war in view of the fuel shortage and of the war, with the result that opinions favored an increase of 50 per cent. in industrial lighting in spite of an opinion that it ought to be decreased in every other branch of the lighting field, such as street, public building and commercial lighting. The figure of 50 per cent. increase appears to have been a conservative opinion because of the opinion of these same experts that without regard to the war conditions and the recent fuel shortage, industrial lighting standards could well be increased by 175 per cent. These opinions, it will be noted, favored marked increases in the quantity of light used for factory operations.

Now the codes of lighting recently issued by the several states who have given this matter special attention, contain tables of the quantities of light as a minimum and as desirable for given classes of work. These quantities have been based on the objective feature of safeguarding the workmen. They have not been based directly on the values desirable from the standpoint of maximum production at the least labor expense, for the simple reason that the state departments of labor are primarily concerned in regulations for the protection of labor, physically speaking. If a table of quantities of light for various classes of work were to be prepared on the basis of the most favorable production rates, there would be a strong tendency materially to increase the values found in these state lighting codes. In the past the magnitude of the increases in the quantities of light over and above the minimum values required by considerations of safety to the eyesight of employees and as a safeguard against accidents, has

[2] Paper on "Lighting Curtailment," by Preston S. Millar, Trans. Illuminating Engineering Society, Vol. xiii, No. 2, p. 126.

largely been based on individual experiences in various cases. To a large extent this condition prevails also at the present time.

### RECENT TESTS ON LIGHTING AND PRODUCTION RATES.

To ascertain the desirable quantities of light to use on a basis of production rates calls for study of the rates of production under different quantities of light ranging from lower to higher values, keeping all other factors in the management of the plant as nearly unchanged in the given section as possible while the investigations are under way. Obviously, this is a task of considerable difficulty and data of this nature have been slow to materialize. Reports[3] on tests in a number of plants in the Chicago district show what appears to be an interesting relation between the production rate and the intensity of illumination provided at the work. In one plant, for example, increases in production of 8 to 27 per cent. in various operations followed an increase in the intensity of illumination from 4 to 12 foot-candles, the lower and higher values having been in use for two consecutive months. These figures tend to verify the close relationship existing between adequate light and the rate of work, and the figures just quoted also contain the further interesting commentary on costs of light in that a general figure is given in the report that by the expenditure for better lighting of about 5 per cent. of the pay roll in a plant section, a 15 per cent. increase in production can usually be secured, this conclusion being based on the above and other tests in the Chicago district.

### RELATIONS OF GOOD LIGHT TO ACCIDENTS.

The above relations of good light to production contain the basis for much help in the education of shop management up to a higher appreciation of the advantages of such facilities. There is, however, the other important aspect of light as a factor in industrial accidents. For adequate data on this phase of the subject we may turn profitably to the Casualty Insurance Companies, because their interests are intimately connected with accident prevention, and if lighting is a material factor, it would naturally be one of the items of the shop equipment to engage the attention of such casualty companies.

From such sources reports from time to time have shown

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[3] A Paper on "Productive Intensities," by Wm. A. Durgin, Trans. Illuminating Engineering Society, Vol. xiii, No. 8, p. 421.

that the industrial accident rate in this country is influenced to quite an extent by improper or inadequate light. In fact, the extent of this influence has been expressed as equal to about 18 per cent. at the present time; that is to say, about 18 per cent. of all industrial accidents are said to be due directly or indirectly to poor, or what may be termed defective, lighting conditions.[4] This may be interpreted as the quivalent of so much labor loss per annum and estimates place this loss as the equivalent of removing about 100,000 workmen from American industries for an entire year each year. The similar estimate for the labor loss due to accidents from all causes has been set as the equivalent of removing about 600,000 men for an entire year each year, so that the loss due to poor light is seen to be about one-sixth of the total. In 1910 the per cent. of total industrial accidents chargeable to poor light, directly or indirectly, was set at about 24 per cent., although the investigation of the records of the particular Casualty Insurance Co., on which the figure was based, resulted in a figure of about 10 per cent. in 1910 for the accidents due primarily to poor light, whereas the remaining 14 per cent. represented cases where poor lighting was merely a contributory cause.[5] Apparently the figure of about 24 per cent. for 1910 may be compared roughly with the more recent figure of 18 per cent. for 1918, on the basis of which the conditions seem to have improved slightly in the eight-year interval.

### HIGH ACCIDENT RATE IN WINTER MONTHS.

An interesting conclusion has been drawn from the well-known curves of Mr. John Calder, first published in the Transactions of the American Society of Mechanical Engineers, as showing the increase in the number of accidents in the industries which are fatal for that part of the year in which normal day hours from 7 A.M. to 6 P.M. are partially dark. This conclusion[6] indicates that the number of accidents in the months of December and January are usually greater than the number that would be expected from the curves if the same amount of light (daylight)

[4] A Paper on "The Relation of Light Curtailment and Accidents," by R. E. Simpson, Trans. Illuminating Engineering Society, Vol. xiii, No. 8, p. 431.

[5] A Paper on "Illumination and One Year's Accidents," by R. E. Simpson, Trans. Illuminating Engineering Society, Vol. x, No. 9, p. 870.

[6] See reference given in footnote 5, p. 869.

existed in winter as in summer. In fact, the increase based on the given curves has been set at 40 per cent.

To the foregoing figures there might be added many convincing descriptions of specific cases where poor lighting has been the primary cause of accidents, both fatal and less serious, as compiled from the experiences of the Casualty Insurance Companies, and these would tend to confirm the general conclusions just mentioned concerning the relation between light and industrial safety. The fact that poor light is a large factor in accident hazard has probably been covered sufficiently, however, to indicate why state labor departments have begun to include lighting regulations among their industrial rules as one of the important factors in the whole campaign of accident prevention and the safeguarding of the life and limb of industrial employees.

### ENGINEERING DETAILS OF NATURAL LIGHTING.

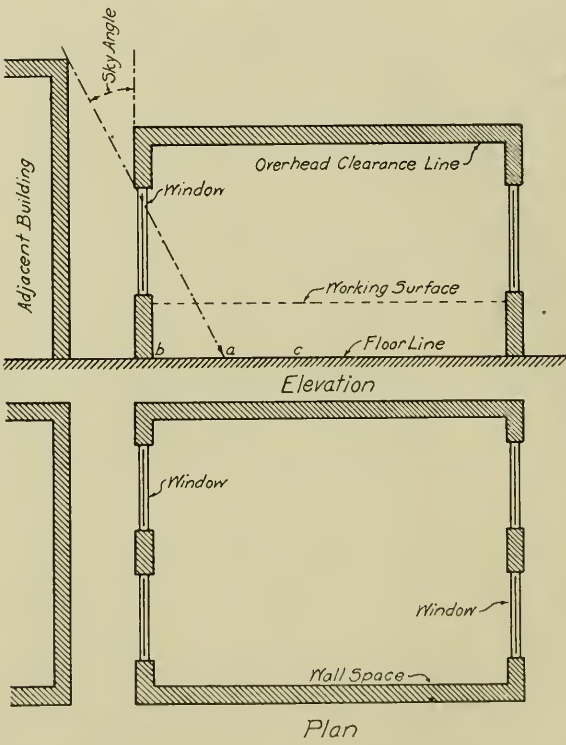
The engineering details involved in planning for natural lighting facilities are fundamentally more difficult than those for artificial illumination because of the extremely variable nature of the daylight throughout given days and for the same hour of the day at different times of the year. Furthermore, many factors, such as the use of side windows which supply natural light in a manner not symmetrical to the floor space, and the presence of nearby structures to impede the light, make it very difficult to assign definite rules for daylight planning.

The general trend of development in the desgin of modern factory buildings has been to employ larger and larger proportions of window space, until extremes have been reached in some cases and the natural illumination has been made excessive and uncomfortable to the employees housed in such structures. Architects and other factory construction designers tend to work towards constants such as certain ratios of window area to floor area in their plans, and this can be made a good basis, provided such constants are used with due regard to the fundamental points involved. Without using proper care in the application of such constants, window planning reduces to little more than a rule of thumb calculation, and the results may be good or bad, depending on the nature of the factors which surround the structure.

To illustrate the attitude taken towards the use of such constants it may be in place to mention a very caustic letter which I received some time ago from a party interested in the problem

of reducing structural daylight plans to a simple formula basis. I had taken the attitude that due to the large number of factors involved, set rules were difficult to formulate. This I still feel to be the case, although the tendency of well-designed factory buildings to adhere to fairly well-defined ratios of the window to the floor space may be taken to indicate the possibility of using such figures for new structures with proper precautions.

Fig. 1.




SOME FACTORS INVOLVED IN DAYLIGHT PLANNING.

I shall endeavor in the following paragraphs to show, first, some of the factors which the plans for interior natural lighting include, and then to point to the basis which may be taken in the formulation of simple rules for such work. First, consider the effect of adjacent structures. A window which might admit a generous supply of daylight is often rendered more or less useless by the presence of a taller building located only a short distance away. This is shown in the upper part of Fig. 1 by the line

passing from the upper part of the structure on the left, through the top of the window to the floor within. Any point on the bench surface to the right of the intersection of this line with the surface receives no direct light from the sky through the left window. Similarly, no point on the floor to the right of *a* in the diagram receives any light directly from the sky through the left window. This does not mean, of course, that those parts of the floor to the right of *a* are in darkness, but the light must come from reflections from the opposite building face or from reflections from those parts of the building interior which receive light directly from the sky, as far as the left window is concerned. The actual daylighting effect in such a building might be decidedly different from that in an exactly similar structure where such an obstruction (that is to say, the building on the extreme left) did not exist, and it is just such a factor that the constants of ratio of window to floor area cannot in themselves well include.

### MULTIPLE STORY BUILDINGS.

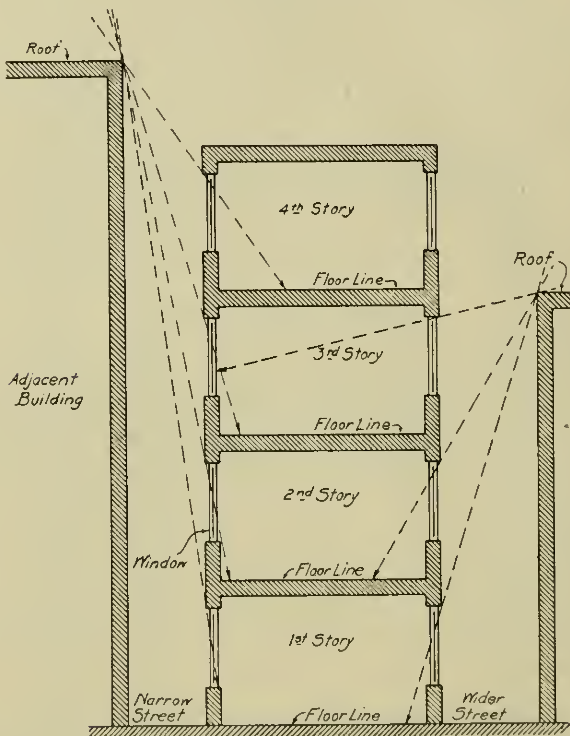
Similar obstruction effects are often very pronounced in the lower floors of multiple story buildings. Note in Fig. 2 the fact that the window to the right in the fourth floor admits light directly from the sky all the way across the room, whereas the effect of the taller structure to the left is to curtail to a considerable extent the effectiveness of the fourth floor window on the left. Left windows on the first floor are practically useless as far as any light directly from the sky is concerned. Effects of this kind are experienced daily in the offices of tall office buildings in congested parts of the city, where artificial light is required continuously throughout many days in spite of the normal window areas provided.

An inspection of Fig. 2 will show that if the ratio of window area to floor area is specified from tables of such constants without regard to differences in the effectiveness of the windows for the various floors, the actual illumination will vary considerably for different floors unless some special devices, such as suitable prisms, are used for the lower floors to re-direct the light over wider floor areas than is possible with plain window glass. Put in another way, a set rule for the ratio of window area to floor area, in a case like Fig. 2, might give adequate interior lighting for the upper floors but it might be very inadequate for the lower floors.

LIGHT TRANSMITTED THROUGH WINDOW GLASS.

Fig. 3 indicates the decrease in the per cent. of light transmitted through plain window glass in terms of the light incident upon the outer surface of the window for various angles of incidence, the definition of angle of incidence as here employed being expressed by the small auxiliary diagram at the top of the figure.[7]

Fig. 2.

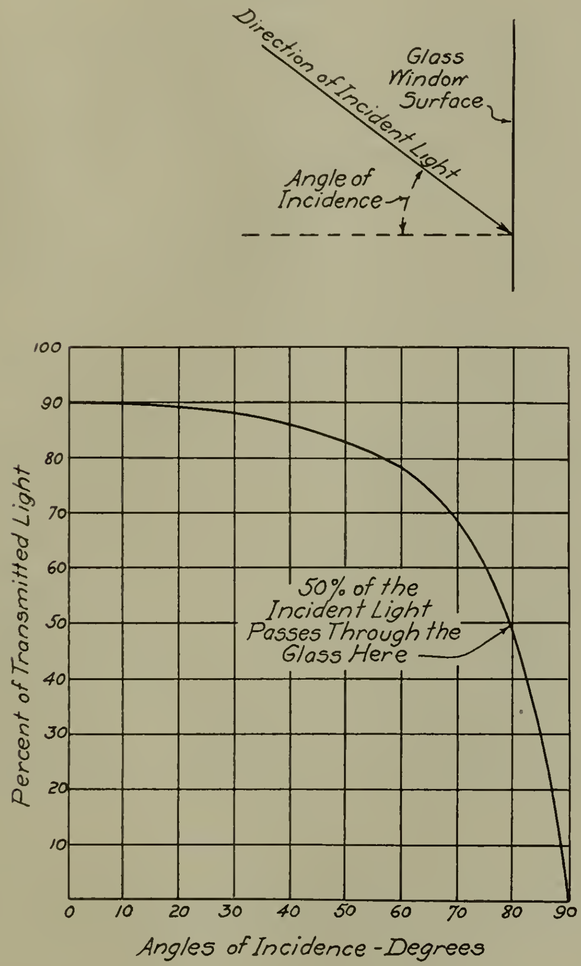



This diagram illustrates the importance of rather low angles of incidence for plain window glass if the per cent. of transmitted light is to be large. Where the angles of incidence are high, as with the lower story windows of tall buildings with other tall buildings opposite, the amount of transmitted light for plain glass is reduced, in general, according to this curve, and the necessity

[7] See "Principles and Design of Interior Illumination," by L. B. Marks. "Lectures on Illuminating Engineering," *Johns Hopkins Press*, Vol. ii, p. 663. See also *Metal Worker, Plumber and Steam Fitter*, Jan. 4 and 18, and Feb. 1, 1918.

of special types of glass for the re-direction of the light into the building becomes relatively greater. This curve starts with 10 per cent. at zero angle of incidence, meaning that plain window glass is assumed to absorb about 10 per cent. of the light normally

FIG. 3.




incident upon its surface. I am indebted to Dr. Peter A. Callan, of New York City, for a reference to the work of Sir William Crookes, about 1909, on glass. He mentions what is termed glass No. 187, made up of fused soda flux 83 per cent., and cerium

nitrate crystallized 17 per cent., for which the claim is made that 99 per cent. of the light incident to the surface is transmitted.[8]

TYPES OF FACTORY WINDOW GLASS.

The use of types of glass other than plain glass for factory windows has received considerable attention. The well-known tests of Prof. Chas. L. Norton, of the Massachusetts Institute of Technology, along this line, may be summarized as follows: (*a*) That the common rough plate or hammered glass has very little action as a diffusing medium, giving no perceptible change in the effective light within the building; (*b*) that the light in a room 30 or more feet deep may be increased from 3 to 15 times its present effect by using factory ribbed glass instead of plain glass in the upper sashes; (*c*) that of the ribbed glasses, the factory ribbed with 21 ribs to the inch is distinctly the best, and not, in all probability, because of the fineness, but because of the greater sharpness of the corrugations; (*d*) that ribbed wire glass is about 20 per cent. less effective than the ordinary factory ribbed glass; (*e*) that prism glass, like the factory ribbed, is more effective in increasing the light when the light is restricted, as in a narrow alley or light shaft, than when the window has an open exposure with a wide sky angle; and (*f*) that rooms with windows opening upon light shafts and narrow alleys with very limited sky, where the available light is now small, may have the light 20 feet back from the windows increased ten to twenty times by using prisms.[9]

The Aberthaw Construction Company has derived the following conclusions from information they have gathered, namely, that (1) the ribbed glass, prices being equal, is under all conditions better than the rough or hammered glass, giving more light under favorable conditions and as much light under all conditions; (2) the objection due to dirt and dust collection on the rough surfaces can be obviated; (3) prism glass is really worth while and will positively increase the amount of light under certain conditions; and (4) ribbed wire glass is about 20 per cent. less effective than ordinary factory ribbed glass.

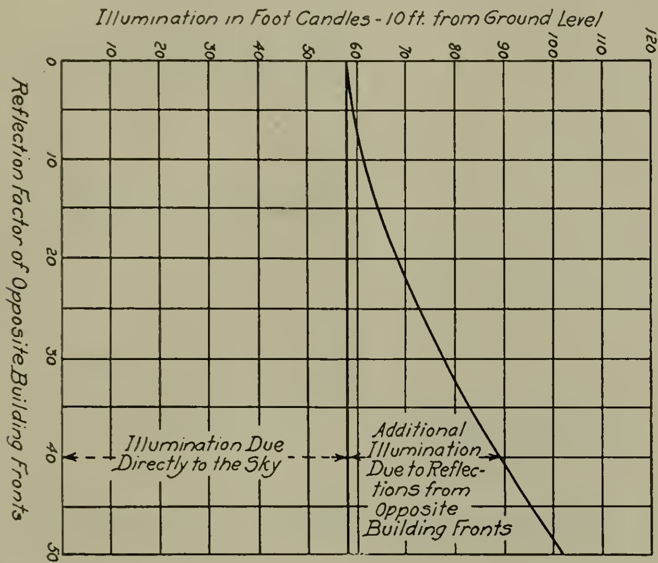
[8] Philosophical Transactions of the Royal Society, London, Series A, Vol. ccxiv, pp. 1, 25.

[9] From information submitted by the Aberthaw Construction Company, for the use of the Employment Management Division of the War Industries Board, 1918.

REFLECTIONS FROM OPPOSITE BUILDING FRONTS.

The effect of reflections from opposite building fronts has been investigated and the curve in Fig. 4 shows the results for various reflection constants of the adjacent or opposite building faces.[10] The curve here shown is based on three reflections from

FIG. 4.




the opposite building front, and indicates the importance to interior lighting in relatively narrow streets faced on each side by high buildings of having the fronts of the building light colored. Factors of the kind just discussed show that various factory buildings of the same general outlines and with equivalent ratios of window to floor area may have widely different daylight illumination effects throughout their interior working surfaces.

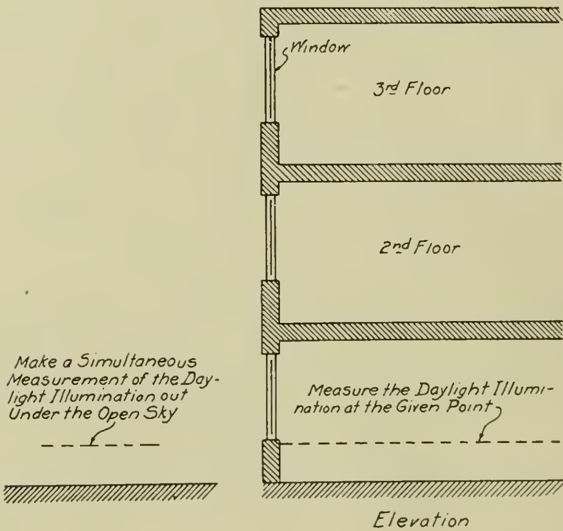
THE DAYLIGHT FACTOR.

It is of interest at this point to consider the natural illumination within a factory in comparison with that at a point outside the building under the open sky. These differences have been commented upon from time to time by various writers, but their significance to the interior lighting problem, particularly in older

[10] See reference quoted in footnote 7, p. 665. Based on original tests of C. O. Basquin.

structures, may readily be overlooked. The ratio of the illumination intensity at a point within a factory to the intensity at the same point, if it were exposed to the open sky, may be termed a measure of the daylight efficiency of a building for the given point, and it is sometimes called the "daylight factor" for the given point.[11] A simple suggested method for determining the

Fig. 5.




daylight factor for a given point within a building is shown in Fig. 5. Average values of the daylight factor in a report issued by the British Government range from 0.25 to 2.3 per cent. for given cases investigated, of course with values above and below these averages, and the lowest values referring to day lighting with side windows only.

The extreme variations of exterior natural illumination intensities are suggested by Fig. 6,[12] which shows the conditions for June, September and December in one geographical location. It is now possible to work out for any given daylight factor corresponding to one or more points within a factory, what the intensities of

[11] Suggested by A. P. Trotter and subsequently developed by P. F. Waldram. See the First Report of the Departmental Committee on Lighting in Factories and Workshops, London, 1915, p. 38.

[12] See footnote 11, p. 64, of the Report referred to. Some daylight measurements in this country may be found in Trans. I. E. S., Vol. xi, No. 3.

FIG. 6.

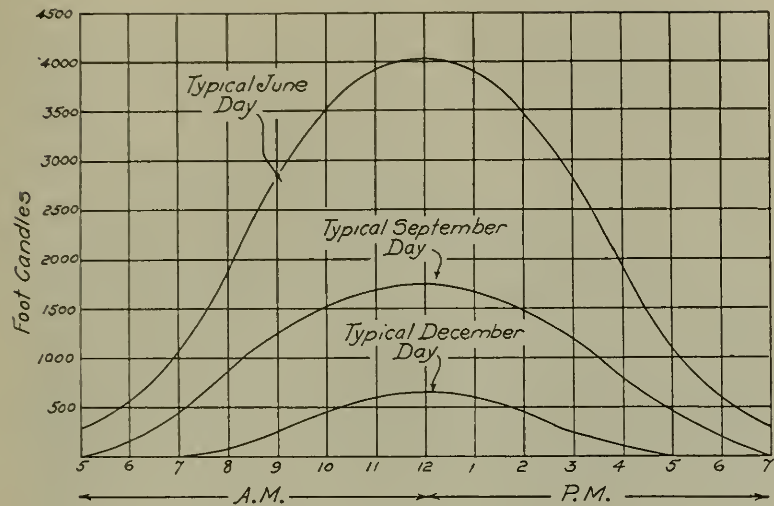
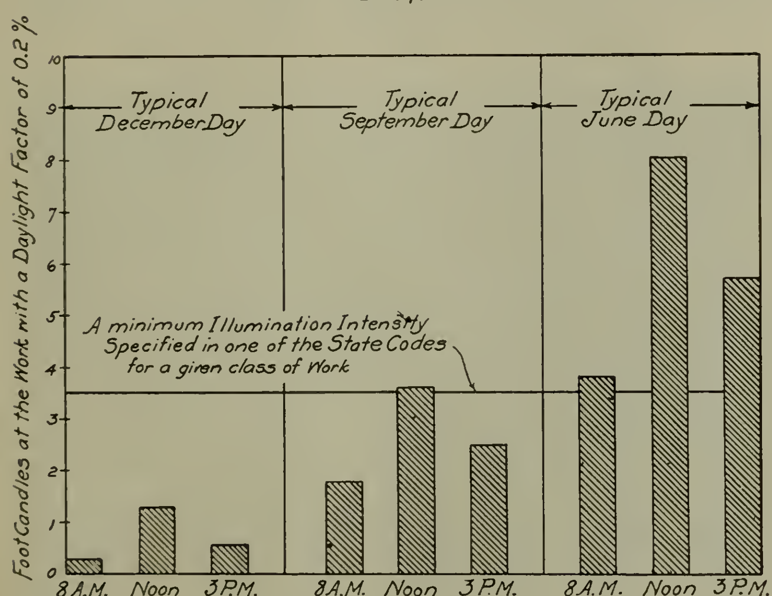

4500
4000
3500
3000
2500
2000
1500
1000
500
Foot Candles
Typical June Day
Typical September Day
Typical December Day
5 6 7 8 9 10 11 12 1 2 3 4 5 6 7
A.M.
P.M.

FIG. 7.

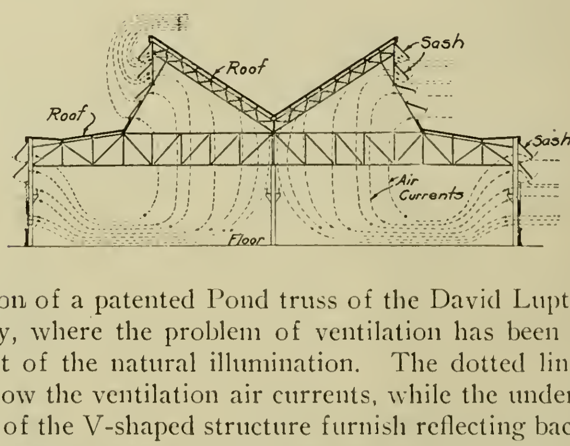

Foot Candles at the Work with a Daylight Factor of 0.2%
10 9 8 7 6 5 4 3 2 1 0
Typical December Day
Typical September Day
Typical June Day
A minimum Illumination Intensity Specified in one of the State Codes for a given class of Work
8 A.M. Noon 3 P.M.
8 A.M. Noon 3 P.M.
8 A.M. Noon 3 P.M.

natural lighting will probably be at different hours of the day and for different days of the year. This may be done in conjunction with a set of curves similar to those in Fig. 6 corresponding to the geographical location in question. Fig. 7 indicates the intensities for 8 A.M., at noon and at 3 P.M. for what may be called typical December, September and June days and shows that for the assumed daylight factor the intensities fall below 3.5 foot-candles all day on typical December days and for a part of the day on typical September days. Values worked out on this basis could readily be used to show roughly the number of hours per day for various months when the daylight should be supplemented by artificial light.

### MODERN FACTORY BUILDING CONSTRUCTION.

The structural developments in factory building design have been quite marked in recent years. Fig. 8 indicates, for example,

Fig. 8.




the section of a patented Pond truss of the David Lupton's Sons Company, where the problem of ventilation has been combined with that of the natural illumination. The dotted lines in this figure show the ventilation air currents, while the under concrete surfaces of the V-shaped structure furnish reflecting backgrounds for re-directing the daylight, admitted through the upper windows, to the floor beneath, and thus tend to distribute the daylight uniformly on the working surfaces throughout the shop. Fig. 9 indicates one of these buildings in the process of construction, while Fig. 10 shows the interior of such a structure after completion. Some idea of the uniformity of the interior illumination may be gained from this view.

The expense of steel sash for factory windows is roughly equal to the equivalent wall area under certain assumptions as to the thickness of the walls and the types of construction in-

FIG. 9.

FIG. 10.

volved. As the area of window space increases for given floor space, however, the heating facilities for the maintenance of a given temperature during winter months also increases and tends to offset the advantages which might be claimed for indefinitely increasing the sash area. Thus it has been found in one given case that the use of side wall windows instead of continuous sash, with a decrease in glass surface and a corresponding increase in solid wall area, would result in a less costly heating plant, the

Fig. 11.

heating plant with continuous sash and the increased glass area for this particular case costing about 10 per cent. more than where side wall windows with a decreased glass area are employed. These figures apply, of course, to one given case only. (Reported by Mr. E. U. Smith.)

The regulation of windows and continuous sash for ventilation purposes is of course important, and in Fig. 11 the ability to open the long lines of so-called Lupton continuous sash is demonstrated, such motion being possible either by hand or by power operated devices.

The possibilities of highly adequate daylight facilities through

properly designed buildings are probably apparent from the foregoing notes. Specific rules would be desirable for window planning in factory buildings, but the above shows that the problem is complicated by factors of design. Simple rules will doubtless materialize, and in fact it would be possible here to append ratios of window area to floor area for a great variety of factory structures, but they may readily be obtained by anyone interested in the problem from the sash manufacturers and, moreover, it is well to remember that such figures, in themselves, may at times be misleading and should only be applied to a proposed new building if they include in their application such important considerations as typified by (*a*) adequate daylight in all parts of the building during normal daylight hours; that is to say, the suitable distribution of the light; (*b*) the avoidance of extremes in glare, and (*c*) proper limits, without prejudice, of course, to the adequacy of the natural illumination, governed by heat losses where window areas are made too large and where the heating costs increase correspondingly.

### ENGINEERING DETAILS OF ARTIFICIAL LIGHTING.

The comparative simplicity of the design of artificial lighting systems in contrast to those for natural lighting has already been referred to as being due partly to the possibility of a more symmetrical arrangement of lamps, when mounted overhead, and when referred to the working surfaces which are distributed through the floor space, than where side windows are depended upon as the sole source of the natural light. This is made clear by a comparison of Figs. 12 and 13. In Fig. 12 it will be noted that there is a lack of symmetry in the distribution of the daylight on the floor area, the intensities being greater near the side wall windows and fairly deep shadows being cast on the floor near the centre of the room. Of course, it is apparent that if roof lighting is employed, the distribution of daylight can be made much more uniform than in Fig. 12, but roof lighting is limited to single story buildings or to the top floors of multiple story structures. Fig. 13 shows a factory space with the artificial lighting system in use at night. It will be noted in Fig. 13 that the distribution of light over the entire floor and working areas is unusually good, due to the symmetrical arrangement of the mercury vapor lamps over the ceiling area. This view also indicates in an exceptional manner the great advantage in the use of medium-sized lamps for

FIG. 12.

FIG. 13.

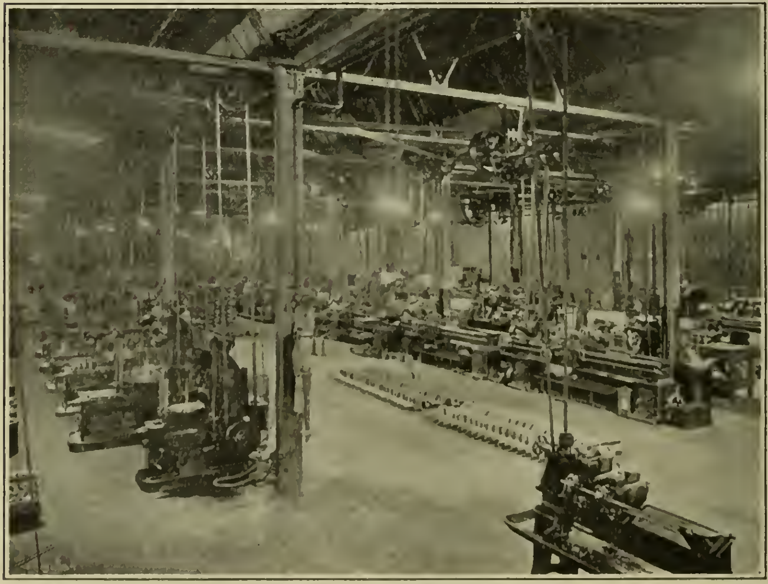


FIG. 14.

FIG. 15.

factory spaces with intermediate ceiling heights such as here shown.

TYPES OF LAMPS.

The principal types of electric lamps now used for factory lighting are the Mazda and the mercury vapor types. Arc lamps, although used to some extent in earlier practice, have given way in many cases for interior industrial purposes to the other types. A typical Mazda lamp installation is shown in Fig. 14, while Fig. 15 shows a section of the Gould and Eberhardt works at Irvington, N. J., equipped with mercury vapor lamps. In addition to the lamps down the central part of this aisle, it will be noted that the same type of lamp is employed under crane runways on either side of the aisle for the illumination of benches and nearby floor space. Either system, that is to say, with Mazda or with mercury vapor lamps, can be planned so as to give excellent results, and quite a number of industries make use of both systems, employing the mercury vapor lamps in those parts of the shop where the particular quality of light from such sources is considered as meeting the special needs of the work, and the Mazda lamps in other departments.

REFLECTORS FOR MAZDA LAMPS.

With the Mazda lamps the need of reflectors is particularly great on account of the character of the distribution of the light from the bare lamp, and also because of the great brilliancy of the lamp filament. In fact, the design of any industrial lighting system should be based upon a careful study of the reflectors to be used with such lamps, if the system is to be effective and highly efficient in the utilization of the available light. Fortunately, a good deal of attention has been given to reflector design and the types now on the market are sufficient to meet ordinary needs provided they are selected intelligently. Standards, which take into account the factors which the reflector should accomplish and the proper points in the design of the reflector to meet these factors, have been developed, and it is planned to market such a standard line of lamp auxiliaries under the trade designation of the R L M standard.

An interesting development in recent reflector design has been worked out in the so-called " Reflecto-Cap " type, in which a small cap is placed beneath the lower part of the lamp bulb, thus protecting the eyes of employees from the brilliancy of the filament itself.

The inner surface of this close-fitting cap is finished so as to be a good reflector and thus re-directs a fair proportion of the light that would ordinarily go downward to the under side of a large metal reflector placed above the lamp. This scheme approximates an increase in the area of the light source and produces a less harsh effect than that of a system in which the bare filament of the lamp is visible. A system of lighting making use of this Reflecto-Cap unit is shown in Fig. 16, and the excellent quality

FIG. 16.

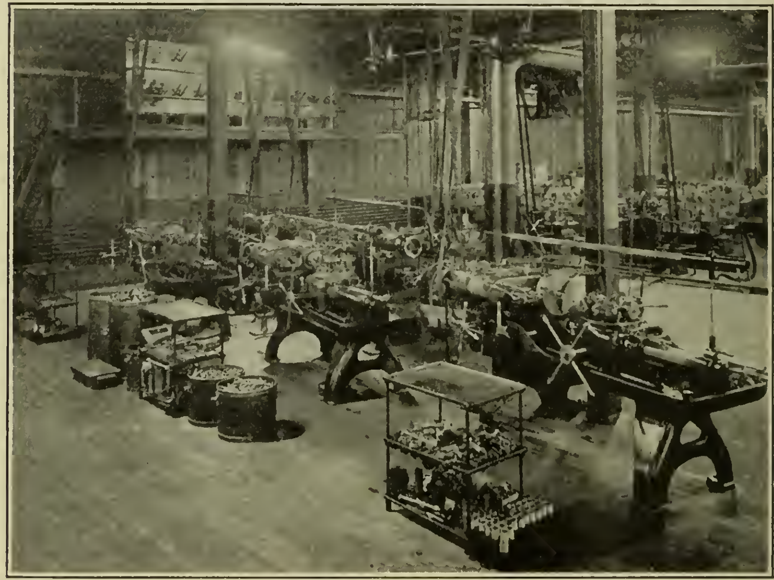
and distribution of the light is evidenced, to some extent, by the freedom of shadows on the floor space, in spite of the numerous machines in this shop.

THE OVERHEAD VERSUS THE LOCALIZED SYSTEMS OF LIGHTING.

In Fig. 17 a good example is shown of what may be termed the overhead or the general system of factory illumination, these terms being used to distinguish it from the older, although frequently used system of local lamps placed close to each machine or directly above and close to each bench surface. In older practice, it was often found that some general illumination from overhead lamps was desirable in addition to that of lamps close to individual

machines. The function of the general illumination in such cases was to furnish some light to the spaces between machines and in the aisles, the latter spaces ordinarily being provided with a less intensity than the points of work directly under the local lamps. The possibilities of using Mazda and mercury vapor lamps overhead and in such density of numbers as to furnish highly adequate illumination over the entire floor area, has led to quite a general adoption of this method of lighting by many progressive plants.

Fig. 17.



The illumination of the entire floor space of a factory section to an intensity adequate for accurate workmanship might seem at first to be an uneconomical procedure inasmuch as a part only of the floor space is usually so used at any one time. However, the following advantages commend it as worth while: (*a*) With every part of the floor space equally well lighted, work may be conducted at any point of the floor without regard to the location of the lamps. This makes it possible to arrange the work, the benches, assembly and other operations, in such a way as to facilitate the sequence of operations and so as to accommodate the best scheme of routing materials, without any regard to the

lamps. If it becomes desirable from the standpoint of manufacture to move a bench or to rearrange the location of some of the machinery, local lighting nearly always requires some readjustments of the lamps and the wiring, which is not only expensive but a decided inconvenience. (*b*) The prevalence of shop accidents in aisles and spaces adjacent to machines rather than at the machines themselves, indicates the importance of adequate light not only at the machinery but also in the adjoining spaces. The general overhead system obviously takes care of this point. (*c*) Moreover, the idea that machine tools should have a local lamp or lamps close to the working position of the operator is often erroneous. Where the general lighting is made adequate in intensity and where the side component of the illumination is sufficient from overhead lamps to illuminate successfully the sides of the work in such machines, the problem may readily be solved, in many cases by the overhead scheme, without resorting to individual or local lamps.

### INTENSITIES OF ARTIFICIAL LIGHTING.

Three principal points stand out in the design of any factory lighting system, namely, *the quantity of the illumination* to use for given classes of work, *the proper distribution* of the light, and *the avoidance of glare*. These points, without regard to other items which must often also be taken into account, are fundamental to the success of the average system. Although the quantity of light is often popularly looked upon as the item of greatest importance, at the present time the avoidance of glare may be taken as probably more vital to the interests of eyesight than either of the other items just mentioned. This statement is based upon the unusual neglect of factory owners to employ shielding devices, such as reflectors or shades, with the brilliant Mazda lamps which are now so commonly used. It may be noted, however, that while the use of reflectors is practically fundamental to the avoidance of glare with Mazda lamps, the use of reflectors also bears very closely upon the other two factors of quantity and of distribution of light.

It is well to note that a comparison between natural and artificial lighting indicates that the ordinary intensities of natural light are far in excess of those which can economically be looked for, or which are even necessary with artificial lighting. The eye possesses a marked degree of flexibility in the illumination

intensities with which vision is possible and comfortable. A simple test of this is to read a newspaper in the elevated or subway surface cars just before entering the subway from daylight conditions and to note that little effort is required to continue reading comfortably under the electric car lamps, although the intensity of the artificial light may be very small in comparison with the intensity of the previous daylight. Another impression may be gained of these large differences by noting that interior intensities of 50 or more foot-candles are common near windows by day, whereas at night, reading may be done comfortably with artificial lighting intensities of, say, two or three foot-candles; that is to say, only 5 per cent. of the foregoing daylight value. This means that due to the peculiar adaptability of the eye to lower intensities of artificial illumination at night, it is not necessary to provide nearly as high intensities with an artificial lighting system as would at first be supposed based merely upon what might be termed daylight standards. When artificial light is required to supplement inadequate daylight, however, then it becomes more important to consider higher intensities of the artificial illumination because of its direct competition under such circumstances with daylight values.

## INTENSITY STANDARDS.

The whole question of intensity values to employ for any given demands upon vision, such as those imposed by various classes of work or different degrees of refinement in the discrimination of detail in the objects looked at, is one which does not yet seem to have been conclusively demonstrated. Illuminating engineers, and in fact practically anyone who is called upon to decide how much light to furnish for given working operations, usually depend upon their judgment, which is often based upon conditions which have seemed satisfactory in other similar locations. This scheme is safe as far as it goes, but it is very difficult to tell when a given system is satisfactory from every standpoint of vision. I have seen a lighting system installed which was far superior to the older system that it superseded, but which, at the same time, was inferior to a still better system that was later proposed. Here the employees thought the second improved system was very satisfactory because of its comparison with a very much inferior system. The judgment of the employees here, if taken on a basis of what was considered satisfactory, might have

been materially different from what it would have been had they been asked for an opinion under a still more nearly ideal arrangement of lamps.

I feel strongly that the specification of the proper quantity of illumination to use for varying visual demands is a matter which is far from solved, and that probably the only way in which it could ever be solved positively would be to take ophthalmological observations upon given observers under a given class of work for different degrees of illumination intensity and over sufficiently long periods to take into account the effects of the illumination upon permanent depression of the eyesight. Temporary judgments based on casual observations do not take into account this factor of long continued use of the light and hence lack at least one element involved. The excellent work of Ferree and Rand at Bryn Mawr College has given to the lighting art a good deal of useful information along this general direction.

### SAFETY STANDARDS OF INTENSITY.

There is another side of intensity specifications, however, which can be approached with somewhat more confidence, and this is the matter of providing enough light to safeguard employees against accidents and to specify minimum values below which manufacture cannot well be conducted without a likelihood of time losses and inaccuracies in workmanship. The state codes now in force in several of the states, which have been based on the code prepared by the Committee on Lighting Legislation of the Illuminating Engineering Society,[13] have included specifications on this *minimum* basis, and then usually add for each class of work a higher value, which is headed as a *desirable* intensity.

In the preparation of tables of suitable intensities of illumination for all classes of work, and for the various ramifications of manufacture, two difficulties present themselves, the one being a lack of information on just what the illumination requirements are for these almost infinite operations, with their varying shades of form, color and detail, and the second being the cumbersome extent of such a list which would endeavor to cover all cases. In the original code of the Illuminating Engineering Society, all industrial processes were summarized under the four heads: (*a*) Storage, passageways, stairways, and the like; (*b*) rough manu-

[13] Mr. L. B. Marks, of New York City, Chairman.

facturing and other operations; ($c$) fine manufacturing and other operations; and ($d$) special cases of fine work. Later, these lists of classification groups have been elaborated somewhat, although the Illuminating Engineering Society's code has been based on this general scheme of classification through its revisions, with the addition of several groups. There is a tendency in one and another of the state codes to amplify the lists of operations and to specify intensities for a larger number of detailed cases.

### DISTRIBUTION AND GLARE.

The question of how the light should be distributed over a factory floor area is one which must be determined by the density of the work and how near an approach may be desired towards a perfectly uniform condition throughout the entire floor space. Reflectors perform an important function in the correct distribution of light from lamps, which, by themselves, might not result in nearly so satisfactory a lighting system.

The avoidance of glare is of the utmost importance, and has already been touched upon. In its simplest form, the avoidance of glare is approached by the workman when he surrounds his otherwise bare local lamp with a piece of paper, or hangs up a piece of cardboard in front of the lamp so as to prevent the strong light of the lamp from shining directly into his eyes. From several standpoints, the proper attention to this feature in the lighting system is one of the most important items of all, and one authority has gone so far as to say, in effect, that if no other improvements were made in existing systems of factory lighting than the equipment of each lamp with a suitable reflector so as to cut off from the eyes all direct rays from the brilliant filaments, that considerable improvement would probably be made in the reduction of industrial accidents. Obviously, the reduction of eye strain and the improved workmanship, which such a course would promote, would also be decided advantages.

### MAINTENANCE OF THE SYSTEM.

The effects of light colored surfaces for walls, ceilings and columns have long been recognized as quite a factor in the effectiveness of lighting conditions, both natural and artificial. White or light-tinted paints and frequent cleaning are two factors to consider. The reader is referred to the lecture on the "Principles of Interior Illumination," by Cravath, Harrison and Pierce, in

the volume of lectures given under the joint auspices of the University of Pennsylvania, and of the Illuminating Engineering Society,[14] in which valuable data are given regarding the variations in the utilization efficiency of various systems of light in its dependence upon wall and ceiling conditions. One of the paint manufacturers has recently issued a readable bulletin under the heading of "Barrelled Sunlight" which very appropriately emphasizes this phase of factory lighting.

It will, perhaps, be seen that no lighting system can maintain its original effectiveness unless the lamps and reflectors are cleaned at proper intervals and unless burned-out lamps are renewed promptly. This is of such fundamental importance to the continued success of any lighting system that some space might well be devoted to the importance of maintenance and to methods for conducting such work, in preliminary reports submitted to building owners on proposed lighting systems. Lamp and reflector cleaning are items which are so readily overlooked that the average user of light requires education along this line if his appreciation of the needs of the case is to result in systematic adherence to the work. One of the best plans I have ever seen of this kind is that adopted some years ago at the East Pittsburgh Works of the Westinghouse Electric and Manufacturing Company, where the maintenance of the very large lighting system is conducted by a special Division of the electrical department. Here, the original plans of the work included systematic inspection of all lamps each day for the purpose of locating every burned-out lamp and for noting equipment in need of cleaning. On the basis of these daily inspection reports, the maintenance work may be conducted effectively and a record can be kept of the costs for such work which forms an interesting basis for a comparison between the costs of the maintenance work and the gains produced by the higher standard of illumination thus maintained.

### STATE REGULATIONS.

The original code of factory lighting issued by the Illuminating Engineering Society several years ago has since been used as the basis for state regulations in Pennsylvania, New Jersey, Ohio, New York and Wisconsin. Furthermore, the Committee on Labor of the Advisory Council for National Defense issued

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[14] Published by the McGraw-Hill Book Company, New York, 1917.

through its Divisional Committee on Lighting [15] a code based quite largely on that of the Illuminating Engineering Society. Many of these codes contain modifications in the general arrangements or in the addition of explanatory matter not found in the original Illuminating Engineering Society's code, but the three fundamental items of *intensity, distribution* and the *absence of glare* form, for the most part, an important place in all of these regulations.

The issuance of the state codes has, of course, been based on the safeguarding of employees and they have sought to reduce accidents and to prevent premature eye trouble by the stipulation of safe methods and amounts of illumination for various factory operations. In one of the recent state codes, the factor of conserving time by permitting employees to do more and better work, without additional effort, in a given time, through the medium of better light, was emphasized as a factor which might influence the wealth of the state.

Realizing that the state factory inspectors, upon whom the application of these codes fall, would probably find difficulty in grasping the full meaning of such rules because of the newness of some of the ideas they contain, the University of Pennsylvania invited state factory inspectors of Pennsylvania and of New Jersey to a series of lectures on factory lighting at the University in the spring of 1918, and these proved to be very acceptable to the state labor departments concerned. I am informed that the Department of Labor of New Jersey is planning to continue this general scheme of education among its factory inspectors by lectures within the state from time to time.

Where intensity of illumination is specified, as in these relatively new codes, the need of a simple device for the measurement of illumination by relatively inexperienced people has been keenly felt. The appearance of the small and very convenient "Foot-Candle-Meter" (see Fig. 18), as a result of the work of Dr. C. H. Sharp, of New York City, has, in a way, met this need, and it is, I believe, employed to a limited extent by the Departments of Labor in Pennsylvania and New Jersey.

### PROBLEMS ADDED BY THE WAR.

While the stress of war conditions is now largely over, it is

[15] Of which Mr. L. B. Marks, of New York, is chairman.

interesting to review, in conclusion, a few of the things which affected lighting practice due to those unusual conditions. One of these, of course, was that of protective lighting about industrial plants as a safeguard against damage to the plant, and this type of illumination received a good deal of attention and was employed very effectively in many cases. Another was that of lighting curtailment, as one of the points taken up by the Federal

FIG. 18.

Fuel Administration, and here, as previously stated, it was found that of all the divisions of lighting, the industries were the one field in which increases rather than curtailment in lighting were desirable, thus emphasizing the importance with which the problem of industrial lighting was viewed during the war as a strictly war problem.

The emphasis which was placed upon good light by the Employment Management Division of the War Industries Board in its efforts to educate employment managers under the intensified training scheme then in vogue, and the hope which was entertained that a high standard of working environment—that is to say, good light, fresh air, adequate heat, cleanliness and neatness about the

plant, and the like—would all go to prevent the excessive turnover of labor during the progress of the war in the war industries, all go to demonstrate the important place which industrial lighting holds in the industrial field.

The foregoing notes, while not in any sense a scientific analysis of factory lighting from the quantitative side, have given a general outline of the factors involved in the problem. With these in mind and thoroughly accepted and appreciated, the actual detailed planning for industrial lighting systems possesses the possibility of an interesting field for study and certainly contains an element of compensation for those who devote time to such work, through the beneficial effects which good lighting may accomplish for those whose vision and whose workmanship depend to such an extent upon facilities of this general nature

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**Salt Deposits of the United States.** W. C. PHALEN. (*U. S. Geological Survey Bulletin No. 669.*)—The Delaware Indians made salt from brine springs in New York State and sold it to settlers as early as 1670, making probably the first commercial production of salt in this country. The manufacture of salt by white people in the United States was begun near Syracuse, N. Y., about 1788. Salt is the most commonly used mineral in the world, and no useful mineral except coal, perhaps, occurs in greater abundance or is more widely distributed in the United States.

The Federal and State Surveys and private establishments have published a great deal about the occurrence of salt in parts of the United States, but not until now has so much information on the salt deposits of the whole country been assembled in a single volume. The distribution and character of the salt deposits are described by States and a brief history of the industry is given, together with a record of the output since 1797. The report also contains a discussion of the origin and formation of saline deposits and many chemical analyses of brines and bitterns.

**Wood Waste.** (*Weekly News Letter, U. S. Department of Agriculture*, vol. vi, No. 47, p. 5, June 25, 1919.)—A particularly interesting field of possibilities for greater utilization of wood and wood waste as a result of the Forest Products Laboratory's war work is the use of built-up and fabricated construction. This is merely utilizing small pieces of wood and a glue which will make a joint as strong or stronger than wood, and building them up in the forms desired. It was found, for example, that a laminated wing beam for airplanes could be constructed as strong as a solid beam, and this at once made possible a great increase in the utilization of spruce material which otherwise had to be eliminated from aircraft construction.

# HIGH FREQUENCY CURRENTS ON WIRES.*

BY

J. O. MAUBORGNE, Lieut. Col., Signal Corps, U. S. A.

ATTENTION was first directed, in 1911, to the practical utility of employing high frequency electric waves for transmission of energy along wires by Major (now Major-General) George O. Squier. The discussion following the publication of his results indicated that, in the minds of many, the opinion prevailed, that because of the excessive attenuation obtaining at the "ultra audio" frequencies, the system would be inoperative over great distances. This was thought to be particularly the case if frequencies greater than 100,000 cycles per second were employed.

Recently this subject has assumed an important aspect from a military standpoint and it was decided to conduct further experiments with the object of examining the possibility of adapting certain existing types of radiotelephone and telegraph apparatus to multiplex operation. The results of the few preliminary tests which have been made recently by First Lieut. R. D. Duncan, Jr., and Radio Engineer Samuel Isler of the Engineering and Research Division, Signal Corps, Washington, D. C., are of interest because they have shown that not only is it possible to transmit energy, at least in sufficient amounts to actuate standard "radio" receiving apparatus, over comparatively long lengths of wire circuits, but that frequencies considerably in excess of the value hitherto named as the upper limit could be employed.

The apparatus used in these tests is known as the SCR-67, which is the ground set of the standard ground-airplane radiotelephone equipment. It comprises two, three-electrode vacuum tubes, of the transmitting type (Type VT-2. One oscillator and one modulator) and connected circuit, a receiving tube (Type VT-1) and circuit, and a two-stage audio frequency amplifier. The method of modulation, that devised by Heising, is based on the fact that, to a very close approximation, the amplitude of the high frequency current is directly proportional to that of the

* Communicated by Maj.-Gen. George Owen Squier. An abstract of this paper was presented at the Washington Meeting of the American Physical Society, April 25, 1919.

*emf* applied between the plate and the common filament terminal of the oscillating tube; any variation of the *emf,* for example, at an audio frequency, will modulate or mould the continuous flow or high frequency energy in a corresponding manner, which when received by a tuned receiving circuit and rectified, manifests itself as an audible sound in a telephone receiver. The means by which the modulation is accomplished is by a second tube, whose plate filament path resistance is varied in accordance with the speech frequencies applied to its input terminals. By properly interconnecting the plate or output circuits of the oscillating and modulating tubes, and by further converting the high voltage plate power supply to the two tubes from a constant potential to a constant current system the variation in amplitude of the high frequency current may be made to follow out faithfully the variations impressed by the modulating source. This system is advantageous since the completeness and purity of modulation is practically independent of the frequency of the oscillating system.

The line may be connected to the source of oscillations in a number of ways, of which probably the most convenient is by inductive coupling.

To provide a practical means for carrying out of the tests, a wire, running from Washington, D. C., to New York City, was placed at the disposal of the Signal Corps by the Postal Telegraph Company. This line was duplexed and was in continuous operation by the Postal Company. In the first series of tests one multiplex station was established at the Signal Corps Radio Laboratory, Bureau of Standards, Washington, D. C., and a second at Dixon's Park, Curtis' Bay, Md., approximately three miles from the Postal office in Baltimore, the total wire distance between the two approximating 60 miles. The multiplex apparatus was connected to the line at these two points.

Satisfactory two-way communication was obtained; speech was received at both stations, loud and with exceptional clearness, the distortion common and inherent to long distance wire telephony being completely absent. The tuning at the receiving stations was quite definite, comparable in every respect to that when receiving signals of a " sharply " tuned radio station. This last fact permits of the operation of a number of multiplex units, each tuned to a different frequency and without the use of filter circuits on the same wire line. The carrier frequency employed in these tests was 600,000 cycles per second (wave length 500

metres); the effective line current, measured at each of the transmitting stations, averaged 60 mil-amperes. Throughout the tests the operation of the multiplex apparatus in no way interfered with that of the wire telegraph apparatus nor was interference experienced from the latter.

The satisfactory range of an SCR-67, when operating as a ground "radio-telephone" set, in communication with a corresponding SCR-67, is, under ordinary conditions, 10 miles. Thus by confining and directing the flow of energy to a definite direction, the range is materially increased.

The advantages of multiplex telephony and telegraphy are many. From a military standpoint alone, it is obvious that in time of war, any means of increasing the traffic handling capacity of already overburdened telephone and telegraph lines will be of inestimable value. There is a further advantage from an economical standpoint, in that certain of the existing types of Signal Corps radio-telephone and telegraph apparatus, large quantities of which were purchased during the war and which are now idle, with only slight changes in construction, may be adapted to either radio or multiplex operation. The increased range obtained makes possible the connection of outlying military posts and establishments with low power units where ordinarily comparatively high power and consequently heavier apparatus would be required if strictly radio communication were solely relied upon.

OFFICE OF THE CHIEF ENGINEER,
ENGINEERING AND RESEARCH DIVISION, SIGNAL CORPS.
WASHINGTON, D. C., April 5, 1919.

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**Tunneling Under the East River.** (*Scientific American*, vol. cxx, No. 26, p. 681, June 28, 1919.)—A very interesting bit of tunneling was recently done on the 14th Street tube under the East River, New York. The heading was being run in rock and at one point test holes showed a thickness of only eight inches of sound dry rock above the line along which the top of the tunnel was to run. As the tunnel was being driven without the use of compressed air it was decided to drop the upper heading four feet until this thin cover of rock was passed. The cast-iron lining was set in place at each side of this section and then the rock was removed very carefully by using a great many holes each loaded with about one-eighth of a stick of dynamite. As each bit of rock was removed to the arch the tunnel lining was set in place. By this means the dangerous section was tunneled without breaking through the thin shell.

**Simple Gage for Measuring Compressions.** ANON. (*Scientific American,* vol. cxx, No. 18, p. 453, May 3, 1919.)—One of the most common causes of lost power in an automobile is that the force of the explosion pressure depends upon compression pressure before the gas is ignited. If the compression is 80 pounds the explosive force acting against the piston top and imparting power to it will be about 400 pounds per square inch. If worn piston rings or leaky valves allow gas to escape when the piston is rising on its compression stroke, the resulting decrease to 50 or 60 pounds means a reduction of explosive pressure to about 300 pounds per square inch. Besides this diminution in pressure, there is a loss due to further leakage through the faulty retaining members.

A simple compression pressure indicating gage may be made by taking an old spark plug body, from which the porcelain has been removed and fit in a valve from a discarded inner tube by pouring melted babbit metal or solder in to fill the space between the spark plug shell and the valve. When the metal has set, the valve is found to be firmly imbedded in the soft metal. The spark plug is removed from the cylinder to be tested and the combination plug body and valve stem put in its place. As the engine is turned over briskly by either the hand crank or self-starter by an assistant, or the engine run slowly on the other cylinders, a tire pressure recording gage held against the valve will record the compression pressure just as it does air pressure inside a tire. If the pressure is low on all cylinders it is a good indication that the entire engine needs attention. It can be determined whether the compression is adequate by comparison with the same tests on a new car of the same model.

**Failure of Concrete Stacks.** ANON. (*Power Plant Engineering,* vol. xxiii, No. 12, p. 543, June 15, 1919.)—From the day concrete made its advent in building construction, its merits were fully recognized. It must be admitted that for a large number of structures there is actually no better material than concrete. It became evident very soon, however, that it is an entirely unsuitable material for any purposes where it is subject to attack of heat, products of combustion, or undiluted acids. One of the best structures in which such conditions prevail is the chimney.

For the moment, we do not want to discuss those where the structure collapsed during the construction or soon after. We refer for the present only to those which decayed rapidly soon after being put in use. The thin walls of the stack permitted rapid radiation of heat. Condensation took place on the inner side of the stack, and the condensate worked its way into the fissures, rapidly destroying the texture of the material, and attacking the reinforcing steel. The stacks started to lean, to burst open, or collapsed entirely. Recently this inherent defect has been in part overcome by using a lining of burned clay, extending the full length of the stack.

# RADIO TRANSMISSION FORMULAS FOR ANTENNA AND COIL AERIALS.*

BY

J. H. DELLINGER,

Bureau of Standards.

THE aerial of a radio transmitting or receiving set is either a condenser or an inductance coil of large dimensions. It effects the transfer of power between the radio circuits and the ether. The coil aerial has the inherent advantage of serving as a direction finder and interference preventer, but is less effective quantitatively as a transmitting or receiving device than the condenser aerial commonly called the antenna. The practical question, how far can communication be maintained by a coil in comparison with an antenna, is answered by the following formulas, derived from electromagnetic theory. A flat-top antenna is considered, and a rectangular coil. Let $h$ = height of antenna or coil, $l$ = horizontal length, and $N$ = number of turns of wire of coil aerial, $I$ = current. $\lambda$ = wave length, $d$ = distance apart of transmitting and receiving aerials, $R$ = resistance of receiving aerial circuit. The subscripts $s$ and $r$ refer to sending and receiving, respectively. All lengths are in meters.

Antenna to antenna:

$$I_r = \frac{188.\ h_s h_r I_s}{R\lambda d}$$

Antenna to coil:

$$I_r = \frac{1184.\ h_s h_r l_r N_r I_s}{R\lambda^2 d}$$

Coil to antenna:

$$I_r = \frac{1184.\ h_s l_s h_r N_s I_s}{R\lambda^2 d}$$

Coil to coil:

$$I_r = \frac{7450.\ h_s l_s h_r l_r N_s N_r I_s}{R\lambda^3 d}$$

These formulas were derived by the author two years ago and have been found useful in the Signal Corps and Navy work since

* Communicated by the Author. Complete paper to appear as a Scientific Paper of the Bureau of Standards.

that time. Either the equations as here given or the component equations giving the field produced by a given antenna or coil aerial and the received current produced by a given field, lead to the solution of questions of design which it would be difficult to settle by experiment. Such quantitative experiments as have been made have verified the formulas to 25 per cent. or better, some observed values of received current being higher and some lower than the theoretical values.

The actual current received when a coil aerial is used is frequently greater than the formulas indicate, because such an aerial acts both as a coil and as an antenna by virtue of its capacity to ground. This double action of the coil structure is likewise indicated by values obtained for radiation resistance and by the observed directional properties.

The use of the coil aerial is particularly advantageous, as may be seen from the formulas, for short waves. In most cases, the usefulness of the coil increases as its dimensions are made to approach the order of magnitude of the wave length. An advantage of the coil not apparent from the formulas is that its resistance can usually be made lower than that of the corresponding antenna.

BUREAU OF STANDARDS,
April 25, 1919.

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**Waterproof Glues in Automobile Manufacture.** ANON. (*Forest Products Laboratory, Madison, Wisconsin, Technical Notes* No. F-14.)—Some of the new waterproof glues developed primarily for aircraft purposes during the war offer the possibility of overcoming a difficulty that has proved very annoying, both to the automobile owner and to the manufacturer, wherever linoleum is used on the running boards or as a covering for the floor of the car. Ordinary glues which are soluble in water are not very effective in cementing linoleum, and most automobile owners have soon discovered that the glue disintegrates and the linoleum comes loose after the car has been washed a few times.

Casein glues are admirably adapted to this purpose, and if the quality is right and they are properly applied the linoleum should give no trouble during the life of the car. Casein glues are exceedingly resistant to the action of water and retain a very high percentage of their original strength, even after long immersion under water. They are comparatively inexpensive, and the materials from which they are made are readily available in the market. They are applied cold and will set without the application of heat.

## PRESENTATION OF THE FRANKLIN MEDAL.
## MAY 21, 1919.

At the Stated Meeting of the Committee on Science and the Arts, held March 5, 1919, the following resolutions were adopted:

"*Resolved*, That the Franklin Medal be awarded to Sir James Dewar, of London, England, in recognition of his numerous and most important contributions to our knowledge of physical and chemical phenomena, and his great skill and inventive genius in attacking and solving chemical and physical problems of the first magnitude."

"*Resolved*, That the Franklin Medal be awarded to Major General George Owen Squier, in recognition of his valuable contributions to physical science, his important and varied inventions in multiplex telephony and telegraphy and in ocean cabling and directing the Air and Signal Services of the United States Army in the World War."

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## CORRESPONDENCE WITH MEDALISTS.

THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
Philadelphia

OFFICE OF THE SECRETARY

APRIL 8, 1919.

*Major General George Owen Squier,*
*Chief Signal Officer, U. S. Army,*
*War Department,*
*Washington, D. C.*

SIR:

I have the honour to inform you that The Franklin Institute has awarded you The Franklin Medal, founded for the recognition of those workers in physical science or technology, without regard to country, whose efforts in the opinion of the Institute have done most to advance a knowledge of physical science or its applications. The award is minuted as follows:

> "That The Franklin Medal be awarded to Major General George Owen Squier, in recognition of his valuable contributions to physical science, his important and varied inventions in multiplex telephony and telegraphy and in ocean cabling, and his eminent success in organizing and directing the Air and Signal Services of the United States Army in the World War."

The medal and accompanying certificate are being prepared, and I am requested, on behalf of our Management, to extend to you a cordial invitation to come to the Institute on the afternoon of Wednesday, May 21st, to receive this medal and certificate from our President.

A second medal has been awarded to Sir James Dewar, of the Royal Institution, London, and the Earl of Reading has been asked to come to the Institute at the same time to receive it for Sir James.

MAJOR-GENERAL GEORGE OWEN SQUIER, PH. D.
Chief Signal Officer, U. S. Army.
FRANKLIN MEDALIST, 1919.

You and Lord Reading will be asked to be guests of honour at a dinner to be given on the same evening, but in this connection our President, Dr. Walton Clark, will communicate further with you.

I am,

Respectfully,

(Signed) R. B. OWENS,

RBO:S *Secretary.*

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THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
Philadelphia

OFFICE OF THE SECRETARY APRIL 9, 1919.

*Sir James Dewar, D.Sc., LL.D., F.R.S.,*
*The Royal Institution,*
*Albemarle Street,*
*London, W1, England.*

SIR:

I have the honour to inform you that The Franklin Institute has awarded you The Franklin Medal, founded for the recognition of "those workers in physical science or technology, without regard to country, whose efforts in the opinion of the Institute have done most to advance a knowledge of physical science or its applications." The award is minuted as follows:

"That The Franklin Medal be awarded to Sir James Dewar, of London, England, in recognition of his numerous and most important contributions to our knowledge of physical and chemical phenomena, and his great skill and inventive genius in attacking and solving chemical and physical problems of the first magnitude."

The medal and accompanying certificate are being prepared, and the Earl of Reading, your Government's Ambassador Extraordinary and Plenipotentiary at Washington, has been requested to come to the Institute on the afternoon of Wednesday, May 21st, to receive this medal and certificate, on behalf of his Government, for you.

I am,

Respectfully,

(Signed) R. B. OWENS,

RBO:S *Secretary.*

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THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
Philadelphia

OFFICE OF THE SECRETARY APRIL 9, 1919.

*The Earl of Reading, Ambassador Extraordinary,*
*and Plenipotentiary of His Britannic Majesty.*
*British Embassy,*
*Washington, D. C.*

YOUR EXCELLENCY:

I have the honour to inform you that The Franklin Institute has awarded to Sir James Dewar, of London, England, The Franklin Medal, founded for the "recognition of those workers in physical science or technology, without

SIR JAMES DEWAR, D. Sc., LL. D., F. R. S.
Jacksonian Professor of Experimental Philosophy, University of Cambridge;
Fullerian Professor of Chemistry, Royal Institution, London.

FRANKLIN MEDALIST, 1919.

regard to country, whose efforts in the opinion of the Institute have done most to advance a knowledge of physical science or its applications." The award is minuted as follows:

> "That the Franklin Medal be awarded to Sir James Dewar, of London, England, in recognition of his numerous and most important contributions to our knowledge of physical and chemical phenomena, and his great skill and inventive genius in attacking and solving chemical and physical problems of the first magnitude."

The medal and accompanying certificate are being prepared, and I am requested, on behalf of our management, to extend to you a cordial invitation to come to the Institute on the afternoon of Wednesday, May 21st, to receive this medal and certificate from our President, on behalf of your Government, for Sir James.

A second medal has been awarded to Major General George Owen Squier, Chief Signal Officer, United States Army, in recognition of his scientific and technical achievements, especially with relation to communications.

You and Major General Squier will be asked to be guests of honour at a dinner to be given on the same evening, but in this connection our President, Dr. Walton Clark, will communicate further with you.

I am,

Your Excellency's very humble servant,

(Signed) R B. OWENS,

RBO:S *Secretary.*

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WAR DEPARTMENT

OFFICE OF THE CHIEF SIGNAL OFFICER

Washington

APRIL 11, 1919.

*Major R. B. Owens,*

*Secretary, The Franklin Institute,*

*Philadelphia, Pa.*

SIR:

I have the honor to acknowledge the receipt of your communication of April 8, 1919, advising me that The Franklin Institute has made an award to me of The Franklin Medal.

Allow me to express my deep appreciation of the very great honor conferred upon me by the Institute through this award.

It gives me great pleasure to accept, subject to the exigencies of the public service, the very cordial invitation which you have extended to me, to come to the Institute on the afternoon of Wednesday, May 21, 1919, to receive this medal and certificate from your President.

I remain,

Faithfully yours,

(Signed) GEORGE O. SQUIER,

*Major General,*

*Chief Signal Officer of the Army.*

BRITISH EMBASSY
Washington

APRIL 12, 1919.

DEAR MR. OWENS:

I beg to acknowledge the receipt of your letter of April 8th in which you are so good to inform me of the award of The Franklin Medal to Sir James Dewar. It is naturally a great pleasure to me to learn of the decision of The Franklin Institute to confer this honour upon Sir James Dewar, and I trust you will be good enough to convey to the members of the Institute the appreciation which I am sure will be generally felt in Great Britain at this recognition of the work of a British man of science.

I fear that it will not be possible for me to accept your kind invitation to visit the Institute on May 21st in order to receive the Medal and Certificate for Sir James, as I shall have left this country by the date in question unless some unexpected alterations should be made in my plans. The Embassy will, however, be only too glad if they can be of service to you for forwarding this Medal to London.

Believe me,

Very truly yours,

(Signed) READING.

R. B. OWENS, ESQ.,
*Secretary, The Franklin Institute,*
*Philadelphia,*
*Pennsylvania.*

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WESTERN UNION CABLEGRAM.

LONDON, April 21, 1919.

*The Secretary Major Owens,*
*The Franklin Institute* (15 S. 7st),
*Philadelphia.*

Convey to Council grateful appreciation for award of The Franklin Medal. Regret cannot receive it personally owing to poor health. Will write. Accept personal regards.

DEWAR.

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THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
OFFICE OF THE SECRETARY Philadelphia

APRIL 25, 1919.

*Major General James Douglas McLachlan,*
*Military Attaché, British Embassy,*
*Washington, D. C.*

SIR:

I have the honour to inform you that The Franklin Institute has awarded to Sir James Dewar, of the Royal Institution, London, England, The Franklin Medal, founded for the "recognition of those workers in physical science or technology, without regard to country, whose efforts in the opinion of the

Institute have done most to advance a knowledge of physical science or its applications." The award is minuted as follows:

> "That The Franklin Medal be awarded to Sir James Dewar, of London, England, in recognition of his numerous and most important contributions to our knowledge of physical and chemical phenomena, and his great skill and inventive genius in attacking and solving chemical and physical problems of the first magnitude."

The medal and accompanying certificate are being prepared, and I am requested, on behalf of our management, to extend to you a cordial invitation to come to the Institute on the afternoon of Wednesday, May 21st, to receive this medal and certificate from our President, on behalf of your Government, for Sir James.

A second medal has been awarded to Major General George Owen Squier, Chief Signal Officer, U. S. Army, in recognition of his scientific and technical achievements, especially with relation to communications.

You and Major General Squier will be asked to be guests of honor at a dinner to be given on the same evening, but in this connection our President, Dr. Walton Clark, will communicate further with you.

I am,

Respectfully,

(Signed) R. B. OWENS,

*Secretary.*

RBO:S

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THE MILITARY ATTACHÉ
BRITISH EMBASSY

WASHINGTON, D. C., 28 April, 1919.

MY DEAR MR. OWENS:

Owing to my temporary absence from Washington on duty your letter of the 25th of April has only just reached me. I am very pleased to learn from it that The Franklin Medal has been awarded to Sir James Dewar, of the Royal Institution, London, England; and I am very flattered at being invited to receive from your President on behalf of the British Government the medal and certificate awarded to Sir James Dewar.

I much regret that Lord Reading, the present British Ambassador, sails for England on the 3rd of May, and is therefore unable to represent the British Government at Philadelphia on the 21st of May. I should esteem it a favour if you would convey to the President and Members of the Franklin Institute my high appreciation of the honour they have done me in selecting me to take Lord Reading's place on the 21st of May, and my grateful acceptance of their kind invitation.

With the assurance of my high esteem,

I am,

Yours very sincerely,

(Signed) JAMES D. MCLACHLAN,

*Major General.*

*British Military Attaché*

Mc/P

R. B. OWENS, ESQ.,
THE FRANKLIN INSTITUTE,
Philadelphia, Pa.

## PROGRAMME OF MEETING, MAY 21, 1919.

Presentation of The Franklin Medal to Major General James Douglas McLachlan, C.B., D.S.O., on behalf of His Britannic Majesty's Government for Sir James Dewar, D.Sc., LL.D., F.R.S.; Jacksonian Professor of Experimental Philosophy, University of Cambridge; Fullerian Professor of Chemistry, Royal Institution, London.

Presentation of The Franklin Medal to Major General George Owen Squier, Ph.D., Chief Signal Officer, United States Army.

Address:

"Some Aspects of the Signal Corps in the World War." By Major General Squier.

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## PRESENTATION OF THE FRANKLIN MEDAL TO SIR JAMES DEWAR AND MAJOR GENERAL GEORGE OWEN SQUIER.

IN calling the meeting to order the President of the Institute announced that the business of the meeting would be the annual presentation of the Institute's highest award, The Franklin Medal, in recognition of distinguished scientific and technical achievement, and recognized Dr. Harry F. Keller, who made the following statement relative to the work of Sir James Dewar:

*Mr. President:* It was at the May meeting of the Institute, 1914, that you presented the first impressions of the beautiful Franklin Medal to two illustrious men of science. This precedent has since been followed, and so we meet here today for the fifth time to pay our tribute to a pair of savants who in the judgment of the Institute have done most to advance our knowledge of physical science. As chance would have it on the present occasion the time could not have been chosen more happily; for in these days of May our Nation is jubilantly celebrating the return of her heroic sons and exultantly looking forward to the early conclusion of a glorious peace.

And I regard it as a very special and rare privilege, Mr. President, to have been asked to present to you as The Franklin Medalists two scientists who have not only made abundant contributions to our knowledge of physical phenomena, but who also by their great achievements have so conspicuously helped our country and its associates in winning the war. It seems, moreover, peculiarly fitting that one of the medalists should be a native and citizen of Great Britain, while the other was born and bred an American.

In accordance with its established custom the Committee on Science and the Arts has based its recommendations upon the recognition of work in both pure science and applied science, without, however, drawing a sharp line of demarcation. For, well-defined as this line appeared before the war began, it has been largely obliterated during the years of the war, when scientists made patriotism their highest aim, and unstintingly gave their services to their Governments, accomplishing feats which in other times would have seemed impossible.

The first of these medals is to be conveyed to a man whose name for two generations past has been one to conjure with in the camps of chemists and physicists. Sir James Dewar is universally recognized as one of the foremost leaders in the two branches of physical science, and the great wealth of contributions he has made to both includes discoveries and inventions of the highest value and in many fields of research.

Like so many famous men of science, he is a native of Scotland. Born at Kencardine-on-Forth, September 20, 1842, he received his training in the sciences at Dollar Academy and the University of Edinburgh. It was in the latter institution, in 1863, that he became assistant to Sir Lyon Playfair, the Professor of Chemistry. In 1868 he spent a few months at the University of Ghent, Belgium, where the brilliant researches of A. F. Kekulé were then attracting the attention of all workers in organic chemistry.

The scientific career of Sir James Dewar presents itself as a long, unbroken, and almost unparalleled series of triumphs in experimental research. It would be difficult indeed to name another investigator of our time who has to his credit a like rich harvest of discoveries and inventions. The time allotted me here is scarcely sufficient to permit even the briefest reference to his more important achievements. He is one of the few great scientists who have not been hampered in devoting their careers entirely to experimental inquiry. As I have already stated, the subjects of his pursuits lie in the fields of chemistry and physics, or on the border-lands of these sister sciences.

In the earlier years of his career he directed his attention mainly to the coal tar bases, and among the researches he made at this time those on pyridine, quinoline, and their numerous derivatives, were the most notable and important. With the experience

gained in this line of work he then engaged in the study of modern high explosives, and as a member of the Government Explosives Committee, he invented, jointly with Sir Frederick Abel, the smokeless powder, cordite, which is the powder used by the British Government.

But the most extended and most fruitful researches of our medalist are undoubtedly those in which the effects of low temperatures were brought to bear on the properties of matter. Not only was he one of the pioneers but in many respects also the most successful experimenter in the field of low-temperature research. He was the first to liquefy atmospheric air on a larger scale and it was he also who made liquefied gases, like oxygen, nitrogen, hydrogen and fluorine, available for scientific use. By evaporating liquid hydrogen under reduced pressure he succeeded in obtaining solid hydrogen. Most remarkable results were obtained by subjecting various substances to very low temperatures. Thus liquid oxygen was found to be strongly magnetic; pure metals at temperatures approaching absolute zero became almost perfect conductors of electricity; and by the use of charcoal as an absorbing agent for gases at extremely low temperatures the highest vacua were attained. By means of charcoal also gases like hydrogen, helium and neon were separated from the air, and in this way highly important information was obtained as to the constitution of atmospheric air.

The inventive genius of Sir James Dewar was strikingly shown in the construction of the new and very elaborate devices employed by him in the liquefaction and solidification of various gases. The silvered vacuum-jacketed vessel, the Dewar flask, is now manufactured on a large scale for keeping hot and cold liquids for long periods of time under the name of Thermos bottles.

The great versatility and resourcefulness of Sir James and his prodigious capacity for work are further reflected by the great number of researches in which he was associated with other distinguished scientists. They embrace a great variety of subjects in the domains of inorganic and organic chemistry, physics and physiology. Among them special mention should be made of the very extended researches in spectroscopy with George Downing Liveing; the difficult and successful experiments on the liquefaction of fluorine with Henri Moissan; the determination of atomic and molecular constants with William Dittmar and with

Alexander Scott; and studies on the physiological action of light and various chemical agents with John Gray McKendrick.

Advancing years have not impaired Sir James' enthusiasm for research, nor his skill and cunning as an experimenter. In recent years he has made many notable contributions to our knowledge of the radioactive substances, and has successfully solved also various problems of capillarity and surface tension. Truly sensational were his experiments with the stable and long-lived soap bubbles blown in a cryophorus vacuum or in perfectly pure air. They were photographed by him in their natural colors and in various stages of development, appearing uniformly black when the final stage of tenuity was attained.

That the scientific institutions and societies of all countries should have vied with each other in lavishing their highest honors upon a man who has done such marvelous things goes without saying. I shall not attempt to enumerate the many positions of trust and honor he has graced with his incumbency, nor the medals, prizes, and degrees that have been bestowed upon him. We rejoice that as the last but not least of the long list we may now add The Franklin Medal, and that this award is so highly appreciated by the recipient. Unfortunately, as he has cabled the Institute, he is prevented by illness to receive it in person, but we are honored by the presence of a distinguished representative of the British Government, who on behalf of the latter will receive the medal for Sir James Dewar. I have the honor, Mr. President, to present to you Maj.-Gen. James Douglas McLachlan, C.B., D.S.O.

The President, in presenting The Franklin Medal to Major-General McLachlan, said:

*General McLachlan,* the members of The Franklin Institute are appreciative of the distinction conferred upon this meeting by the presence of a representative of the Government of Great Britain; and we thank you personally, Sir, for coming to have a share in our simple ceremony.

The Franklin Institute, having awarded to your distinguished countryman, Sir James Dewar, in recognition of his services to mankind rendered in the field of science, The Franklin Medal and Diploma, and a certificate of Honorary Membership in The Franklin Institute, it becomes my duty and privilege to present to

you this Medal and these documents for transmission to Sir James through the State Department of your Gracious Sovereign. These awards constitute the highest honor in the gift of the Institute.

In accepting the medal for Sir James Dewar, Major-General McLachlan said:

*Mr. President, Members of The Franklin Institute, Ladies and Gentlemen:* I much appreciate the honor that has been done me in inviting me to accept on behalf of The British Government The Franklin Medal awarded by The Franklin Institute to Sir James Dewar. And I should like to express to you how sorry Lord Reading was that he had to sail for England before the date fixed for this ceremony. His commanding presence and his eloquence would have been a much finer means than any words of mine for expressing the pleasure and gratification of the British Government and the British nation at the signal honor done to British Science by the award of this medal to Sir James Dewar. For this is the first time that this high distinction has been awarded to a British subject, and for that reason both I and my country are indeed proud today.

The work and scientific achievements of Sir James Dewar have been set forth in detail by Dr. Harry F. Keller, and I shall not repeat them. But in the minds of soldiers the name of James Dewar will always be associated with two things, firstly, the Thermos flask which he invented, and secondly, the smokeless explosive Cordite, of which he and Sir Frederick Abel were co-inventors.

As a soldier and a Scotsman it gives me great pleasure to receive for Sir James Dewar this medal. For he is a Scotsman and a countryman of mine, and it was in Edinburgh that he first began his studies of chemistry under Lord Playfair.

And another reason why I am glad to have an opportunity of speaking to you today is this: This war has shown how absolutely essential it is to make the fullest use of the chemical, metallurgical, manufacturing and engineering resources of a country in order to ensure success in war. To ensure success in modern warfare all the resources of the country must be utilized strictly for war purposes. If you will look through the membership list of The Franklin Institute you will see how large a number of the members gave their services to the Government

at a time when technical experts such as they were urgently needed. I select two names, the first to come into my mind, that of General Atterbury, who served as Director-General of Railways in France, and that of Mr. Vauclain, Vice-President of the Baldwin Locomotive Works, who did such splendid work on the War Industries Board in Washington and with whom I was constantly in close touch during the war. I know that many other members of The Franklin Institute did equally good work, but I merely mention these two names as typical of the work done by members of The Franklin Institute during the war; and it is of great value to any Government to have an Institute such as this whose members have the technical knowledge of chemical, metallurgical, engineering and manufacturing questions which is indispensable for the adequate carrying on of a great war.

Lastly, I am very glad to have the chance of witnessing the presentation of the medal of The Franklin Institute awarded to my old friend and companion in arms Major-General Squier. It has been my good fortune to know General Squier for over eight years, both in this country and in England, and in addition to the other bonds of friendship that unite us we both had the good fortune to serve in France with the original Expeditionary Force in 1914. For that reason I am particularly glad to be here this afternoon.

I take this opportunity of expressing to you the thanks of Sir James Dewar and of Great Britain for the honor thus conferred for the first time on a citizen of the British Empire. May it cement still further the friendship between the two great English-speaking nations, and may we, together with those great Nations alongside of whom we have fought and won the great struggle in defence of the liberties of the world, may we, I say, all continue to work together in the arts of peace and civilization as successfully and whole-heartedly as we have fought together in the recent great war.

Dr. Keller was again recognized, and presented the following statement of the work of Major-General Squier:

*Mr. President:* It is a well-known fact that under the stress of great national crises individuals are often stimulated to almost superhuman performance, and that tasks which in normal times it would require decades to accomplish, are then done, and well

done, by such men in a few months or years. The great war which has just come to an end has furnished many instances of this sort, but few so remarkable as that of the scientist to whom you are about to present the other impression of The Franklin Medal. By natural inclination as well as by training a military man and a scientist, he achieved such distinction in both capacities that at the time when our country entered the great war he was chosen for the gigantic dual task of building up our Air Fleet and of providing the field telephone and wireless communications for our armies. How nobly and well he acquitted himself of these responsibilities I need not tell you or an audience such as this. I cannot refrain, however, from expressing the thrill of pleasure I experience in presenting to you for the highest award of the Institute a man who has so magnificently served our Country in the great crisis.

Our medalist, Major-General George Owen Squier, Ph.D., is still in the prime of life, and we may well hope and expect that in the years to come he shall gather many laurels to add to those he has won in the war and before it. He was born at Dryden, Mich., on March 21, 1865. He received his military training at the U. S. Military Academy, West Point, N. Y., and it was there that he first showed his decided bent toward mathematical and scientific studies. After his graduation in 1887 he was appointed second lieutenant in the Artillery, and shortly afterwards sent for duty to Fort McHenry, at Baltimore, Md. I venture to say that no assignment could have been made more welcome to the young officer who so ardently aspired to be a physicist. For, close at hand, at the Johns Hopkins University, the chairs of physics, chemistry and astronomy were then held by a trio of the most eminent exponents of physical science, *viz.*, Henry Rowland, Ira Remsen, and Simon Newcomb. And he lost no time in taking advantage of his opportunities, nor were the teachers slow in recognizing the exceptional ability and great promise of their soldier-student. In all three cases the relations between teacher and student were destined to grow into lasting friendships, while the young officer was laying the foundations for those inventions which have since made him famous as a physicist.

His first important contribution to science was a research on "Electrochemical Effects due to Magnetization," published in

1893. Four years later he wrote, jointly with Dr. A. C. Crehore, of Dartmouth, a mathematical paper entitled "Currents in Branches of a Wheatstone's Bridge," and about this time he engaged, partly by himself, and partly in conjunction with Dr. Chehore, in a series of investigations relating to applications of physics to military service. Among the numerous important results of these were the invention of a New Range and Position Finder and the Synchronograph. The latter marked a great step forward in the rapid transmission of intelligence, being based on the use of the alternating current with the polarizing photochronograph as receiver. But this was only the beginning of a great series of achievements by which our medalist advanced and improved the methods of telegraphy and telephony. The "wired-wireless," first proposed by him in 1911, has proved, especially in military field operations during the war, to be invaluable as a means of sending intelligence and commands. As the name implies, it is a method of telegraphing or telephoning by means of electrical waves guided by wires. In this way as many as a half dozen messages may be sent *along* a telephone wire, but *outside* of it, at the same time, and without interfering with the use of the wire for ordinary service. The messages, however, must be tuned to different frequencies and be received by separate receivers. One great advantage of this system is that the waves will still travel along the wire when it is broken and jump gaps in it of fifty feet and more. The "wired-wireless" method of multiplex telegraphy and telephony has recently been adapted and developed for commercial purposes and has proved especially useful on long open wire lines. During the last few years our medalist has devised a new method of ocean cabling which is now in successful operation, effecting a very considerable increase in the capacity of the existing cables. This remarkable stride in cable transmission was made by substituting for the cable "curve," made by opening and closing the circuit, a single-phase alternating current of the sine wave type, operating with the Morse code.

The wire and wireless inventions made by General Squier are bewildering in their variety and number. They extend over the entire range of the transmission of intelligence on land, under the sea and in the air. His studies on the absorption of electromagnetic waves by living organisms led, among other things, to the use of trees as antennæ in wireless telegraphy and the con-

struction of a new listening device, the "floraphone." It was he also who laid the inter-island cable in the Philippines, in 1900, and who drew up the first specifications of a military airplane ever issued by any government. What he did in building up our air fleet and as Chief Signal Officer in our army is too well known to require any commentary at this time and before this audience.

Nor is it necessary for me to recite here the many steps of his promotion from second lieutenant to his present rank of Major-General, which have attended his most brilliant and eventful career in the Army.

Until a few days ago we had confidently expected that General Squier would be with us on this occasion. I know he was looking forward to it with genuine pleasure, but he has quite unexpectedly been ordered abroad. In his absence Dr. F. P. Keppel, Assistant Secretary of War, has kindly consented to come here from Washington to receive the Franklin Medal for him. I have the honor, Mr. President, to introduce to you Dr. Keppel.

The President then said:

*Dr. Keppel,* the members of The Franklin Institute are appreciative of the honor conferred upon this meeting by the presence of a representative of the War Department of our National Government; and we thank you personally, Sir, for coming to have a share in our simple ceremony.

The Franklin Institute, having awarded to our countryman, Major General George Owen Squier, in recognition of his services to our country and to humanity, rendered in the field of science, The Franklin Medal and Diploma, and a certificate of Honorary Membership in The Franklin Institute, it becomes my duty and privilege to present to you this Medal and these documents for transmission to General Squier through the War Department of our National Government. These awards constitute the highest honor in the gift of the Institute.

Dr. Keppel, in accepting the medal for Major General Squier, expressed the pleasure which the War Department felt in having the life-work of General Squier recognized by the highest award in the gift of the oldest institution in America devoted to the development of physical science and its application, and to the encouragement of those whose researches and inventions have served as milestones in the progress of civilization.

Colonel M. McK. Saltzman, Acting Chief Signal Officer, then read the following paper for the medalist:

# SOME ASPECTS OF THE U. S. SIGNAL SERVICE IN THE WORLD WAR.

BY

GEORGE OWEN SQUIER, Ph.D.

Major-General, Chief Signal Officer U. S. Army.

It is with the keenest regret that I find it impossible to be present at the Hall of The Franklin Institute on the afternoon of the 21st of May to receive at the hands of our President The Franklin Medal.

Nothing short of a sudden call for overseas service, from the Commander-in-Chief himself, would have prevented me from being present in person to receive this signal honor from our venerable Institution.

Had I been present you would have expected me, no doubt, to give very briefly the underlying principles which have guided those of us in authority in the making of that part of our expeditionary forces which has to do with the transmission of intelligence in all of its ramifications of personnel and matériel.

This is not the time nor the place to speak in detail of that great enterprise. In the fulness of time these details will be preserved as they should be in the archives of our country. It manifestly can be done only when we can add to the accomplishments of this side of the Atlantic the details of the work of the Signal Corps in actual combat and in the equally important network of communications behind the lines which has been built up not only in France but in England, Italy and Russia and wherever American soldiers have been sent for duty.

It would be quite impossible to mention either the names or the accomplishments of the 2712 officers and the 53,277 men who have been engaged in this great work. Where names are mentioned it is purely incidental to illustrate a point.

This famous Institute itself contributed a conspicuous part in this enterprise. In the early days of the war this Institute for a time was turned into a veritable recruiting station for the Signal Corps, and some 2000 officers and men were by this means available to the Signal Corps, thus gaining most precious time.

The importance of inter-communication in warfare cannot well be exaggerated. The element of time is a controlling one in strategy and tactics, and as the distances become greater the electrical method of inter-communication surpasses all others in

increasing ratio. Unity of Command, which the Allies were so slow in realizing, can reach its full value only when the most perfect system of inter-communication is established and maintained between general headquarters and the larger units and between these and the smaller units to the man on the firing line.

The enormous size of modern armies and vast terrain over which they must operate only accentuates the importance of the intelligence transmission system.

History records from the earliest times the development step by step of methods of signaling. It is known, for instance, that the Indians who inhabited this continent prior to its discovery by Columbus had certain efficient methods of signaling unknown to us at present.

As civilization has progressed science has been called upon at each step to contribute additional means of communication between individuals or groups.

Undoubtedly the most efficient method of signaling yet devised is the spoken word which we employ hourly to signal our thoughts in every shade of their meaning.

The telephone art, which stands to-day as a monument to American genius, and every essential feature of which can be traced to American origin, is efficient over all others for the fundamental reason that it vastly extends the reach of the human voice and permits the use of language directly in signaling. This means that practically every individual is an expert signalman, and in the United States there is no region so remote but that it may not be joined at present to any other region by direct speech.

The advances in radio telephony and telegraphy where the ether of space becomes a common "party line" for all, and particularly the linking up of these ether circuits to the great wire systems of the world, protends the day which I believe is not far distant, when we can reach the ultimate goal so that any individual anywhere on earth will be able to communicate directly by the spoken word to any other individual wherever he may be.

Nor is this linking up of methods of communication restricted to the surface of the earth. To a limited extent we can communicate from distant points above the earth to points beneath the surface of the earth or of the ocean. To-day we are talking directly from the high-speed airplanes above the clouds to the wire systems of the country and ships at sea also can speak from mid-ocean to land stations of the wire system.

It is possible, for instance, for the President of the United States to exercise his functions during residence in Europe which would have been utterly out of the question a few years ago. Indeed, the time is not far distant, it is believed, when the President of the United States may address from the White House practically the entire American people assembled in their respective localities throughout the country to receive his message by his own voice.

The radio lighthouse, which shall mark the aerial highways throughout the land and serve as beacons for the guidance and location of aircraft on every voyage, is an accomplished fact, and these will multiply rapidly as each city and town of the country is brought within the expanding net-work of public and municipal flying grounds.

These lighthouses have certain advantages over the normal lighthouses in that their ranges may be much greater, and they are not invisible in the daytime nor obscured by fog and mist.

Surely no development can surpass in wonder and amazement the accomplishments of radio telephony and telegraphy and certain associated subjects now being realized every hour.

We are on the threshold of the inauguration of what is called the League of Nations and drastic limitations to the enormous burdens which nations in the past have carried in the creation and maintenance of military armaments will, it is hoped, be imposed. The practical execution of the provisions of the League of Nations from the military, economical, social and diplomatic standpoints will depend, it is believed, very largely upon the creation, expansion and maintenance of the most perfect interlinked network of inter-communication, literally covering the land, sea and air. Such a perfect system will be the cheapest and most certain adjunct to effectively carrying out the provisions of this League, and will contribute to a better understanding between nations as will no other agency or instrumentality.

On April 6, 1917; the Signal Corps of the Regular Army consisted of 55 officers and 1570 men, and the problem confronting the Corps was how to provide in the shortest possible time for an installation in Europe as well as in the United States, which should extend from every factory door and training camp throughout the United States to the front line trenches in France.

The Signal Corps is a small compact service ranging from 2½ to 4 per cent. of the Army, which in a peculiar sense serves

all branches of the Army as perhaps no other service does. To illustrate, if at any time prior to the signing of the armistice we were to subtract from the American Army the Signal Corps in its entirety for a single hour, the whole military machine would utterly collapse. This is believed not to be the case to the same extent for any other equal per cent. of the Army. This merely means that this small percentage, which may be called the nervous system of the body of the Army, must be made both in personnel and matériel as efficient and perfect as possible.

Nothing should be left undone which contributes in any manner to the creating and maintaining of the highest efficiency in this small percentage of the Army which adds this vital service.

The advance in the science and art of electrical communication has reached a point where it may be said that the Signal Service stands to-day as a distinctly technical service second to none in the Army.

Realizing the utter unpreparedness of this country at the time we entered the war and having been fortunate enough to have been in Europe with one of the allied armies covering a period of two years of the war, I realized that the only hope of an adequate Signal Service in the shortest possible time was to so arrange matters that the very best trained men in this country already engaged in the telephone, telegraph and electrical industries should be made available forthwith after the outbreak of war.

Our problem was a different one in this country from that of our Allies where the telegraph and telephone systems are already in control of the Government.

Realizing the importance of this, sometime in January, 1917, as I remember it, prior to the entrance of this country into the war, I went to New York and had an informal conference with Mr. Theodore N. Vail, President of the American Telephone and Telegraph Company; Mr. Newcomb Carlton, President of the Western Union Telegraph Company, and in particular with my friend Colonel John J. Carty, in which the general outlines of the procedure in case we entered the war were talked over and arranged.

The problem was, How could we pick from these organizations and other similar utilities the men and equipment needed immediately without crippling that essential service in the United States, where additional demands would be made in the vast industrial preparations required at home also?

Manifestly this could be done only by thorough coöperation between the Government and the guiding heads of these utilities.

The first move therefore made upon the outbreak of war was the commissioning of four or five of the leading engineers and executives in the commercial telephone and telegraph companies of this country and these in turn were charged with the selection and organization of the trained personnel to be sent immediately abroad to start the work while the new army could be trained in this country. These engineers and executives, instead of being brought to Washington in the early days of the war, were left directly at their offices, where they had every facility organized, and they took their orders from the Signal Office in Washington. With the loyal coöperation of the companies themselves it was possible to send to Europe in the first months of the war twelve battalions of the best trained men this country could produce. Each one of these organizations was composed of officers and men who were already technically trained and whose conduct and character were vouched for by the organizations from which they came.

In the meantime, of course, the machinery for a large number of technical schools was set in motion which later produced the flow of field and telegraph battalions required for the combatant troops.

If the Chief Signal Officer had brought this first group mentioned above directly to Washington, as would have been the usual procedure, the time which it would have taken, under the congested conditions necessarily then existing in the War Department, to establish these officers and equip them with the office machinery required, and learn the intricacies of army routine, would have caused the Signal Corps to lose a great deal of valuable time in getting the initial start in France.

During the early months of the war, therefore, these officers in the uniform of their country, installed in their regular offices, with the full machinery at their disposal, represented for a time the United States as well as their former employers, and through the hearty coöperation and loyal support of all hands the Signal Corps was enabled to get under way with the ablest and most experienced technical men in the country in the shortest possible time.

It is difficult to realize to what extent specialization has reached under the impetus of war in the matter of electrical

intercommunication. The mere enumeration of the types of specialists now required by the Signal Corps is a formidable one. In addition to regular special troops in the line branches of the Army this service demands highly trained specialists as follows:

Telephone and telegraph engineers
Traffic and plant experts
Operators both male and female, speaking French, English and German
Installers and maintenance experts
Telephone and telegraph repeater experts
Printing telegraph mechanicians
Traffic supervisors and test-board men
Traffic and wire chiefs
Linemen
Switchboard repairers and installers
Radio engineers, constructors and operators
Electrical research experts
Meteorologists
Photographers—both still and motion
Pigeon fanciers
Optical experts and field glass repairmen
Instrument makers and repairers
Shop practice experts and oxy-acetylene welders
Production experts
Gasoline and motor transport experts
Motorcyclists
Chauffeurs
Dry and storage battery experts
Storehouse managers
Cable experts and operators
Draftsmen

## RESEARCH AND DEVELOPMENT.

In no branch of the military establishment is the need for continual research more necessary than in the Signal Corps of the modern army. Scarcely a single piece of technical apparatus that was regarded as adequate at the beginning of the war is to be found in the Signal Corps equipment at the time of the signing of the armistice. Strong research departments were founded both in France and in the United States and the best men of the country available were assigned to this work. Many of these men were taken from universities and colleges and electrical, chemical, physiological and mechanical specialists were set to work on both sides of the Atlantic to devise new means of supplementing the methods of signaling and associated subjects. In engineering development the demands grew to the proportion of a large indus-

trial plant. The entire facilities of the Bureau of Standards were requisitioned on a large number of special problems and the principal personnel of the Weather Bureau were used in the newly established meteorological service.

It was soon realized that a special laboratory devoted exclusively to development work and entirely independent of the commercial laboratories, such as the Western Electric Company and the General Electric Company, would be needed, and a special laboratory fully equipped for radio development was established at Little Silver, New Jersey, which grew to be one of the largest in the world. Recently this site has been purchased for the permanent use of the Signal Corps and the experience of the present war has clearly shown the necessity for an institution of this sort where trained specialists may devote their entire energies to the new problems constantly arising in the extension of methods of intercommunication now appearing as never before.

The Science and Research Division of the Signal Corps was established in Washington and a mere enumeration of the number of problems which this Division was called upon to investigate and develop shows to what extent all branches of science were drawn upon to perfect this service.

### TRAINING OF PERSONNEL.

It was not possible to take men from the general draft and train them as efficient telephone and telegraph men within the very short time that could be allotted for training, and hundreds of men assigned directly to Field Signal Battalions from the general draft had to be turned back again. The plan eventually worked out was to obtain 75 per cent. of all Signal Corps personnel required, from enlisted men who had completed the course of instruction laid down by Signal Corps schools. These schools were established at the principal colleges, universities and technical schools throughout the country. In addition five large training camps were established as follows:

Camp S. F. B. Morse
Fort Leavenworth
Camp Alfred Vail
Franklin Cantonment
College Park, Maryland

The curriculum was established for these schools and standardized for all, which included a thirteen weeks' technical course.

As to the results obtained in the selection and training of personnel, the following statement was made by Mr. Daniel W. LaRue, Chief Psychological Examiner, upon the completion of his work at the Signal Corps Cantonment, Camp Meade, Md.:

"These facts substantiate what has been found in other camps, that the Signal Corps personnel as a whole have the highest average intelligence as far as the Army psychological examinations can determine."

EQUIPMENT.

The extent of equipment required by a modern army for Signal Corps purposes is beyond what anyone could have dreamed. As an example, a single order for a certain kind of insulated wire was in sufficient amount to extend 14 times around the earth. The cost of Field Glasses alone exceeded $40,000,000, and Wrist Watches for Signal Corps operators alone reached a total in excess of 43,000 watches. Over a million batteries were produced, and 285,000 Vacuum Tubes for radio amplifiers. Over 100,000 telephones for field use alone were necessary, and over 200,000 pliers for use in line construction work. Over 8000 of one single type of Radio apparatus was produced and shipped to France.

The above items constitute but a few of the 267 which are furnished to various branches of the Army as Unit Equipment. In addition to these there are over 2000 items for use by the Special Services and in maintaining communication in the Zone of Supply.

The above brief outline of the quantities of modern Signal Equipment required for the conduct of war as it is now understood teaches above all other things one lesson in organization, which is, that the Signal Corps officer, like a medical officer, must make the Signal Service his life work. Previous to this war the Signal Corps of the American Army was organized by detail from the infantry, artillery, or cavalry, for a period of four years. Having in mind the services which are rendered to each and all branches of the army by this small group of specialists, it is clear that in any plan for reorganization we must first select with great care the young officers for this service and then give them the best training to be found in the country for their work, since it is only by continuous application and study that the Signal Officer can hope to maintain his efficiency.

The supreme test of the Signal Corps, as of all other branches

of the Army, is always to be found in the performance of its tasks under the actual tests of battle and in the military areas which supply and maintain the combatant troops. I cannot better close these brief observations of the Signal Corps than by quoting a letter from General Pershing, the Commander-in-Chief, issued and published to the American Expeditionary Forces under date of February 19, 1919:

> "Now that active operations have ceased, I desire to congratulate the officers and men of the Signal Corps in France on their work, which stands out as one of the great accomplishments of the American Expeditionary Forces—the result of a happy combination of wise planning and bold execution with the splendid technical qualities of thousands of men from the great commercial telephone, telegraph and electrical enterprises of America. It is a striking example of the wisdom of placing highly skilled, technical men in the places where their experience and skill will count the most.
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> "Each Army Corps and Division has had its full quota of Field Signal Battalions which, in spite of serious losses in battle, accomplished their work, and it is not too much to say that without their faithful and brilliant efforts and the communications which they installed, operated and maintained, the successes of our armies would not have been achieved.
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> "While the able management of the directing personnel is recognized, it is my desire that all members of the Signal Corps, who, regardless of long hours and trying conditions of service, have operated and maintained the lines, shall know that their loyalty, faithfulness and painstaking care has been known and appreciated. In the name of the American Expeditionary Forces, I thank them one and all and send to them the appreciation of their comrades in arms and their Commander-in-Chief."

After the reading of the above paper moving pictures and lantern slides illustrative of A. E. F. Signal Corps activities were shown under the direction of Captain A. Bliss Albro, and a number of Signal Corps communication devices, such as T. P. S. sets, trench and airplane radio sets, etc., were exhibited by Captain E. F. Pernot.

**Cements Producing Quick-hardening Concrete.** P. H. BATES. (*Proceedings of the American Society for Testing Materials,* June 24–27, 1919.)—There have been prepared at the Pittsburgh branch of the Bureau of Standards certain cements which have the property of hardening very rapidly. These were made in a manner no different from that used in making Portland cement, but their composition differed very materially from the composition of the latter in that they consisted very largely of lime and alumina. These calcium aluminates, when they are very high in alumina, do not have a very marked rapid initial set, but do harden very quickly and therefore produce high early strengths. Some of the maximum strengths were 3145 pounds per square inch for 1 : 6 gravel concrete, tested in the form of a 6 x 12 inches cylinder, at the end of twenty-four hours, 6010 pounds per square inch at the end of seven days, and 8220 pounds per square inch at the end of one year.

Tests were also made on 6 x 12 inches cylinders in which the bonding material was "Sorel cement." These cements are produced by gauging light calcined magnesia with magnesium chloride solution. The fact that magnesium oxide when mixed with a solution of magnesium chloride will harden was possibly first known by Sorel in 1853; from him it has at least taken its more common name. Such a cement develops in twenty-four hours a strength approximately equivalent to that developed at the end of seven days by a similar concrete made with Portland cement. Both of these cements commend themselves for certain special uses where a quick-hardening concrete of high strength is required. Neither would be desirable where subject to the continued action of water. The Sorel cement alone is on the market at the present time.

**Artificial Stone from Mica and Clay.** ANON. (*The American Architect,* vol. cxv, No. 2268, p. 824, June 11, 1919.)—Mr. Chr. Ingvaldsen, of Saaheim, Norway, claims to have devised a process of making a practicable building stone by mixing finely divided mica with a just sufficient amount of clay or other substance of similar properties, to form a coherent mass, which is then shaped into blocks, plates, and other objects of any desired shape and size. These, it is learned, are then fired at a temperature just high enough to fuse the mass, the resulting stone having in general the same properties as natural mica.

If it be desired to produce stone having greater resistance to high temperatures the process is modified as follows: Instead of mica alone, a mixture of equal parts of mica and of crushed quartz, with just enough clay to act as a binder. The stones formed from this mixture are fired at a temperature high enough to secure the fusing of the mica. The result is a homogeneous mass not only highly refractory to heat, but capable of acting as an electric insulator.

## NOTES FROM THE U. S. BUREAU OF STANDARDS.*

### A SIMPLIFICATION OF THE INVERSE-RATE METHOD FOR THERMAL ANALYSIS.[1]

By Paul D. Merica.

[ABSTRACT.]

THE use of stop-watches in taking inverse-rate curves in thermal analysis is described, and it is shown that they may be substituted for the chronograph, which is often used without sacrificing accuracy or sensitivity. One operator is able to record the successive time intervals for the inverse-rate curve, with their aid, and no time is subsequently required for the reading and counting of the chronograph record; the intervals so recorded may be plotted directly.

### STRENGTH AND OTHER PROPERTIES OF WIRE ROPE.[2]

By J. H. Griffith and J. G. Bragg.

[ABSTRACT.]

*Nature of Investigation.*—The paper presents the results of tests upon 275 wire ropes submitted by American manufacturers to fulfill the specifications framed by the Isthmian Canal Commission in 1912. The samples were selected by government inspectors for acceptance tests of materials to be used at the canal zone.

The rope ranged in diameters from ¼ inch to 1½ inches, a few being of larger diameters up to 3¼ inches. Over half the specimens were plow and crucible cast steel hoisting rope of 6 and 8 strands, 19 wires each. The remainder were galvanized steel guy rope and iron tiller rope of 6 strands, 7 wires and 6 strands, 42 wires, respectively.

The investigation was made primarily to determine the tensile strengths of the ropes. Much of the experimentation was of a supplementary character—to determine the general laws of construction of the rope as the basis of the interpretation of their physical behavior under stress. A comparative analysis was made

*Communicated by the Director.

[1] Scientific Papers, No. 336.

[2] Technologic Papers, No. 121.

of the chemical constituents of steels, rope fibres and lubricants of plow steel ropes submitted by different manufacturers.

*Methods of Tests.*—The wires at the ends of specimens were "frayed out" to form a "broom." These were inserted into moulds, into which molten zinc was poured so as to form conical sockets for connection to the testing machines. Most of the tensile tests were made on a 600,000 pound Olsen testing machine, the ropes of large diameters being tested on the 1,200,000 pound Emery machine. Stress-strain measurements were made on over half the specimens. Numerous tests of individual wires were conducted in tensile, bending, and torsion machines. The strengths of the cables were studied in connection with their modes of construction, the strengths of their component wires, and the types of fractures which were presented.

*Results of Measurements and Tests.*—The homologous linear dimensions of the strands, wires, and fibre cores were found to vary in direct proportion to the diameters of the ropes. The diameters of the strands and fibre cores were generally one-third the diameter of the rope. The mean pitch or lay of the strands was $7\frac{1}{2}$ diameters. The mean lay of the wires was $2\frac{3}{4}$ diameters. The mean diameter of the wires was expressed by the equation:

$$d = K\frac{D}{N+3}$$

$d$ = diameter of wires.
$D$ = diameter of rope.
$N$ = number of wires in outer ring of wires of a strand.

$$K = \begin{cases} 1.0 \text{ for hoisting and guy rope.} \\ 0.8 \text{ for extra flexible } 8 \times 19 \text{ hoisting rope.} \\ .33 \text{ for tiller rope.} \end{cases}$$

The aggregate cross sectional areas of the wires was expressed approximately by the equation:

$$A = C^1 D^2 : C = \begin{cases} .41 \text{ for } 6 \times 19 \text{ plow steel hoisting rope.} \\ .38 \text{ for } 6 \times 19 \text{ cruc. steel hoisting rope.} \\ .38 \text{ for } 6 \times \ \ 7 \text{ guy rope.} \\ .35 \text{ for } 8 \times 19 \text{ plow steel rope.} \\ .26 \text{ for } 6 \times 42 \text{ iron tiller rope.} \end{cases}$$

It was found when the maximum loads determined from tensile tests were platted as functions of the diameters of the ropes that the curves bounding the lower frontiers of each zone comprising the observed values were in close agreement with similar

curves platted from the minimum strengths stipulated in the specification of the Isthmian Canal Commission of 1912. These strengths were also in approximate agreement with the standard strengths recommended in 1910 by the manufacturers from the results of their tests of cables similarly classified. The minimum strengths found from the present investigation are given by the following empirical equation:

$$\text{Load} = C\ 75000\ D^2$$

$D$ = diameter of wire rope in inches.

$$C = \begin{cases} .9 \text{ to } 1.1\text{; mean value about } 1.0\text{; } 6 \times 9 \text{ plow steel cables.} \\ .8 \text{ to } .95\text{; mean value about } .9\text{; } 8 \times 19 \text{ plow steel and } 6 \times 19 \text{ cruc. cast steel cables.} \\ .3 \text{ to } .4\text{; mean value about } .35\text{; iron tiller and steel guy rope.} \end{cases}$$

The modulus of the rope calculated from stress-strain measurement was found to vary from 3,000,000 to 9,000,000 pounds per square inch, depending upon the diameter and class of cable.

Plow steel ropes were selected for comparative analyses of the constituent materials. In the chemical analyses the carbon content ranged from 64 to 96 per cent. with a mean of about 75 per cent. The manganese ranged from 25 to 68 per cent., the silicon from 11 to 24 per cent. The percentage of phosphorous and sulphur was relatively low. In certain cases the steel of the filler wires was softer than the main wires.

The fibres used in making the core of the rope were estimated as manila, jute, istle, mauritius, manila fibre alone being employed by certain manufacturers. The preservatives and lubricants on the cores were composed of wood and vegetable tars, petroleum products, and fish oil, the practice varying somewhat among the manufacturers.

There was a reasonable uniformity in the strengths and elongations of the wires from a particular cable, but a larger variation in the strengths of the wires from cables of different manufacturers. This was probably due to the fact that different grades of plow steel were used by the several manufacturers in meeting the provisions of the specifications.

The cables developed from 72 to 90 per cent. of the aggregate strengths of the wires. The upper limit of the ratio of the strength of a rope to the strengths of its wires was found from theoretical considerations to be 89.2 per cent. for 6 x 19 plow steel cables. The differences between the results of the theoretical analysis and

the practical tests were largely attributed to different strengths and degrees of ductility of the wires, this causing an unequal distribution of the load among the strands with over-stressing of certain strands near the point of failure.

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## NOTES ON THE GRAPHITIZATION OF WHITE CAST IRON UPON ANNEALING.[3]

By P. D. Merica and L. F. Gurevich.

[ABSTRACT.]

1. THE annealing or graphitization ranges of temperatures were determined for three different compositions used for car wheels. The temperature of initial precipitation of temper carbon for six hours of annealing was not noticeably affected by variation of sulphur content from 0.10 to 0.20 per cent. or by variation of total carbon content from 3.60 to 3.90 per cent., although the effect of greater carbon content is to narrow the temperature range within which graphitization is complete.

2. The temperature of beginning precipitation of temper carbon was about 830° for the six-hour period of annealing and about 725° C. for the forty-eight-hour period. The maximum allowable temperature therefore for the annealing or "pitting" of car wheels is about 725° C.

3. After complete decomposition of all free cementite by annealing at from 1000° to 1100° C. and cooling at equal rates in a laboratory electric furnace less graphite is found in a specimen cooled from 1100° degrees than in one of the same composition cooled from 1000° C. This indicates that graphite separates directly from solid solution upon cooling, when its nuclei are already present.

4. The fact that only 0.20 per cent. of combined carbon was found in some specimens after annealing at high temperatures and cooling slowly in the furnace would indicate either that the graphite eutectoid lies at much lower values of carbon content than has been previously supposed, that there is at these rates of cooling a direct precipitation of graphite eutectoid or that there is a formation of graphite from pearlite at temperatures directly below that of its formation.

[3] Technologic Papers, No. 129.

## THE EFFECT OF RATE OF TEMPERATURE CHANGE ON THE TRANSFORMATIONS IN AN ALLOY STEEL.[4]

By H. Scott.

[ABSTRACT.]

COOLING curves taken on an air-hardening steel of the high speed tool steel type show two critical points on cooling from 920° C., one occurring at about 750° C. accompanied by the precipitation of the hardening constituent, the carbide, and the other on fast cooling at about 400° C., under which condition the carbide remains in solution as martensite. On cooling at intermediate rates both transformations are observed and the constituents, troostite and martensite, are detected by the microscope. A transformation is observed on the heating curves taken following a fast cooling which is manifested by an evolution of heat ending at about 645° C., and which represents the precipitation of the carbide held in solution by previous rapid cooling. The resolution of the carbide under these conditions occurs at a temperature some 10 to 15° C. higher than after a slow cooling.

The conclusions drawn support the twenty-year-old theory of Le Chatelier that martensite is a solid solution of carbide in alpha iron.

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**Photographic Evidences of Meter Readings.** ANON. (*Electrical World,* vol. lxxiii, No. 1, p. 36, January 4, 1919.)—The Detroit Edison Company is using a special camera for taking "load test" meter readings to establish customers' demand charge. A regular meter reading camera was rebuilt so that now photographs are taken showing in the picture not only the meter reading but a watch dial with the time of reading and also the name and address of the customer.

The photographic readings have shown their value in a number of instances where differences of opinion have come up with regard to the correctness of load curves. For example, in a case where a customer raised an objection to his bill on the ground that readings were not taken exactly one hour apart, the production of an actual photograph of his meter with the time of taking shown on the same film satisfied him as to the correctness of the load test.

[4] Scientific Papers, No. 335.

**Testing Strength of Joint Glues.** ANON. (*Forest Products Laboratory, Madison, Wisconsin, Technical Notes* No. F-16.)—In using glues for high-grade joint work, a knowledge of the strength of the joint is important. A method which is inexpensive, accurate, and suitable for use in a woodworking factory has not yet been developed. The following method, which is used at the Forest Products Laboratory, can be employed if a universal timber testing machine is available.

Two blocks of selected hard maple, about 1 inch by 2½ inches by 12 inches in size are glued together. After the glue has aged sufficiently they are cut into shear specimens and these are placed in a testing machine so that the base of the long half of the block rests on a metal seat. Pressure is then exerted on the short half, causing it to slide past the long half at the glued point. The pressure required to separate the blocks in this way is measured and the percentage of the area of wood surface torn out by the glue estimated.

If the failure occurs entirely in the glue, a measure of the strength of the glue joint is obtained, but if the failure is entirely or partly in the wood, as frequently happens, the full strength of the glue is not developed and the test may have to be repeated, using stronger blocks.

As the same method has been used in securing data on the strength of wood in shear, when the strength of glue has been determined, it can be compared with that of any wood whose average shearing strength is known.

The Forest Products Laboratory has made thousands of tests on specimens glued with casein and animal glues, and when properly used, these glues have shown shear values of 2400 pounds or more per square inch. Few commercial American woods average more than 2400 pounds per square inch in shearing strength, and the majority of them average less than 2000 pounds. Many glue tests have averaged as high as 3000 pounds.

**How Much Water Should be Used in Concrete?** ANON. (*Scientific American*, vol. cx, No. 15, p. 365, April 12, 1919.)—The Emergency Fleet Corporation, in connection with its work on concrete vessels, has developed an apparatus for testing the amount of water which should be used in concrete work. An open metal cylinder is employed resting upon a glass plate. This serves as a mold which is filled with concrete and smoothed off level on top. Then the cylinder is raised, leaving the concrete on the glass plate. If the mixture is very dry, the concrete will maintain its cylindrical form, but the wetter the concrete the more it flows out at the bottom, so that a measure of the consistency of the mixture can be obtained by measuring the height of the cylinder or cone of concrete after the metal cylinder has been withdrawn.

## NOTES FROM NELA RESEARCH LABORATORY.*

### NOTE ON THE DISTRIBUTION OF ENERGY IN THE VISIBLE SPECTRUM OF A CYLINDRICAL ACETYLENE FLAME.

By Edw. P. Hyde, W. E. Forsythe and F. E. Cady.

A KNOWLEDGE of the distribution of energy in the visible spectrum of an acetylene flame has become important within the last few years through the use of this flame, in cylindrical form, in investigations of the visibility of radiation. It can be shown by computation that the data on acetylene published by Coblentz form a curve in the visible spectrum which will not agree with that of a black body at any temperature to better than 7 or 8 per cent. As this would mean that no color-match could be obtained and as previous experience of the authors had led to the conclusion that the energy curve of acetylene differed in shape from that of a black body only in the extreme red, a short investigation was undertaken to verify this conclusion.

Tungsten lamps whose current color-temperature relation was carefully determined in this laboratory were sent to the Eastman Kodak Company and to the Bureau of Standards with the request that they be compared with the acetylene flame and the current for color match be found. The results gave an average value of 2360° K. ± 10° K., and neither laboratory reported any difficulty in obtaining a match in color. However, the Bureau of Standards reported a difference amounting to about 75° K. between the flame as given by the Eastman standard burner and that given by the "Crescent Aero" burner, the latter being higher.

The spectral distribution of the flame was measured by means of a spectrophotometer and a spectral-pyrometer and the results gave a curve agreeing within the limits of error with that of a black body at 2360° K. In the extreme red, beyond 0.70$\mu$ there was indication of a higher emissivity for the acetylene. A photographic method gave results corroborating those just mentioned.

A test of the sensibility of the color match method to show differences in the spectral energy curve, showed that if two spectral curves matched at 0.5$\mu$ and 0.7$\mu$ and differed by as little as

* Communicated by the Director.

4 per cent. in the middle of the spectrum, the two light sources could not be made to match in color.

In conclusion, it is recommended that the relative emission intensities of a cylindrical acetylene flame, at least for that type represented specifically by the Eastman standard burner and for the wave-length interval from $0.4\mu$ to $0.7\mu$, should be taken as identical with those of a black body at 2360° K.

CLEVELAND, OHIO, June, 1919.

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**American Peat Industry.** ANON. (*U. S. Geological Survey Press Bulletin*, June, 1919.)—The output of crude peat in the United States in 1918 far exceeded that of any preceding year and the general increase, which was stimulated by the war, was shared by practically all branches of the industry. Though extensively used as fuel in Europe and widely known in the United States as a potential source of heat and power, peat has been unable in most parts of the country to compete with coal and many peat operators have therefore directed their attention to the utilization of peat in agriculture with gratifying results.

*Use of Peat in Agriculture.*—Peat fertilizer was first marketed in commercial quantities in 1908, and stock-food peat in 1912, and though there is still some prejudice against the use of these products the agricultural branch of the peat industry has been successful and the quantity of fertilizer and stock-food peat annually produced is increasing. Large quantities of these products were made in 1918, but the most striking development of the year was the production of more peat fuel in the New England States than has been manufactured commercially in the entire United States in all preceding years. Almost equally striking was the widespread interest manifested in our peat resources which had heretofore been generally regarded as of doubtful value.

Large quantities of peat or sphagnum moss were produced and utilized in this country in 1918 for stable litter, packing material, and surgical dressing, and several hundred thousand acres of peat soils were used for the growth of both general and truck crops. The peat litter was produced by the owners of small bogs for their own use, but the packing material was sold to florists for $25 a ton. According to J. W. Hotson, of the American Red Cross, more than half a million peat moss pads were prepared in this country from October, 1917, to November 11, 1918, by the Northwest and Atlantic divisions of that organization. Most of the moss was gathered by volunteer labor from bogs in Washington, Oregon, and Maine, and the pads were used in American military hospitals, both at home and abroad.

The quantity of crude peat produced in the United States in 1918 was 151,521 short tons. The total number of plants at which peat was commercially produced was 25.

## NOTES FROM THE RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY.*

### X-RAY CHEMICAL ANALYSIS.

By A. W. Hull.

The method of X-ray crystal analysis developed in the Research Laboratory of the General Electric Company just before the war is being further developed, as a method of chemical analysis, which promises to have a very wide and new field of application in that it gives evidence which other methods do not supply, namely, the form of chemical combination of each of the elements present.

The method consists in reducing the substance to be examined to powder form, placing it in a small glass tube, sending a beam of monochromatic X-rays through it, and photographing the diffraction pattern produced. The only apparatus required is a source of voltage, an X-ray tube, and a photographic plate or film. The amount of material necessary for a determination is one cubic millimeter. The method is applicable to all chemical elements and compounds in so far as they are crystalline in form.

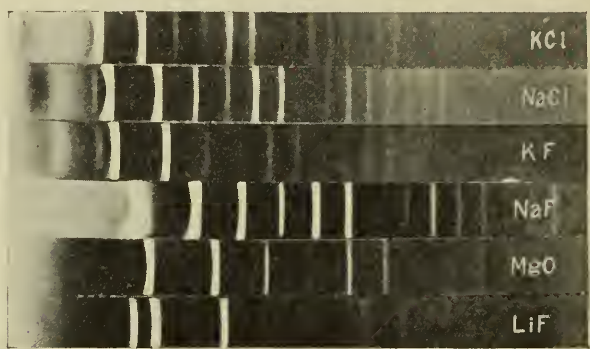
The rays from the X-ray tube pass first through a filter, which absorbs all but a single wave length, then through two slits, which confine them to a narrow beam (about 1 mm. wide); then through the powdered material, which scatters or "reflects" a very small fraction of them; and thence to the centre of the photographic film. An exposure of from one to twenty hours is required, according to the amount of information desired.

When the film is developed it shows, in addition to the over-exposed line in the centre, where the direct beam strikes, a series of other lines on each side of the centre. These lines are caused by the "reflections" of the X-rays from the tiny crystals in the powder. Their distance from the centre of the film depends on the distance between the planes of atoms in the crystal, and there is one line for every important set of planes in the crystal. It is evident, therefore, that subsbtances with different crystalline structures will give entirely different patterns of lines. Substances

* Communicated by the Director.

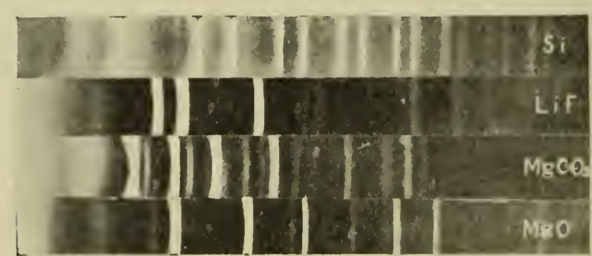
of similar chemical nature and therefore similar crystal structure give similar patterns, but the magnification or spread of the pattern is different for each one, being inversely proportional to the cube root of the molecular volume. Since no two similar sub-

FIG. 1.




stances have *exactly* the same molecular volume it is easy to distinguish them, as the difference is cumulative for lines far from the centre. A further distinguishing mark is the relative intensity of the different lines which differs greatly even in the most closely

FIG. 2.




related compounds, depending on the relative shapes and sizes of the atoms in the compound.

A knowledge of the theory of the production of these lines, and their relation to the crystalline structure of the substance, is not essential to their use for chemical analysis. All that one needs to use in a chemical analysis is the fact that every crystalline substance gives a pattern; that the same substance always gives the

same pattern; that no two different substances give the same pattern; and that in a mixture of substances each produces its pattern independently of the others, so that the photograph obtained with a mixture is the super-imposed sum of the photographs that would be obtained by exposing each of the components separately for the same length of time. This law applies quantitatively to the intensities of the lines, as well as to their positions, so that the method is capable of development as a quantitative analysis.

As illustrations of the general type of photographs obtained with simple compounds and elements, Fig. 1 shows a series of isomorphic alkali halogens, illustrating their similarity of pattern and their differences in spacing and intensity; and Fig. 2 gives a series of dissimilar substances, illustrating their different types of pattern.

Several actual analyses have already been made which will be described in detail elsewhere.[1] It has been found very easy to recognize at a glance each component in a three component mixture and in the case of the simpler salts many more than this could certainly be identified. Accurate quantitative tests have not yet been made, but it is anticipated that an accuracy of one per cent. will be easily obtainable, for components present to the extent of one per cent. or more of the whole sample.

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**Waste of Chemicals in Pulping Unbarked Wood by the Sulphate Process.** ANON. (*Forest Products Laboratory, Madison, Wisconsin, Technical Notes* No. C-5.)—In the manufacture of sulphate and mechanical pulp, all bark must be removed from the wood before chipping or grinding, since any fragment of bark finding its way into the pulp makes its appearance as minute black specks in the finished sheet. For soda or sulphate pulp, the cleaning is often not so thorough, since the alkaline digestion tends to destroy the bark. Some mills bark the wood partly or not at all in the manufacture of sulphate pulp.

To determine the amount of chemical required to pulp unbarked wood, shipments of unbarked shortleaf yellow pine chips and of clear bark were tested by the Forest Products Laboratory of the U. S. Forest Service, at Madison, Wisconsin.

A determination upon a 10-pound sample showed that the unbarked chips contained approximately 96 per cent. wood and 4 per cent. bark, on a bone dry basis. Sulphate pulping trials on clear bark showed that 28.6 pounds of caustic soda and 10.6 pounds of

[1] *J. Am. Chem. Soc.* for June or July.

sodium sulphite were required per 100 pounds of bone dry bark. A yield of 20.9 per cent. of a gelatinous, brownish-black mass, containing pieces of unreduced bark, was obtained. This material could not be screened or washed because it clogged the screen openings. Hand sheets made of it gave physical indications of an extremely hydrated stock, the finished sheets being hard and parchmentized.

The results indicate that in pulping a ton of wood (bone dry), consisting of 96 per cent. wood and 4 per cent. bark, 22.9 pounds of caustic soda and 8.5 pounds of sodium sulphite are needed to reduce the bark. The pulp produced from the bark is useless and, furthermore, produces a variation in color of the pulp, which makes it difficult to mantain a uniform shade in the finished paper.

**Experiments With Mixtures of Acetylene and Coal Gas.** ANON. (*London Gas Journal,* vol. cxlv, No. 2904, p. 22, January 7, 1919.)—Satisfactory results are said to have attended experiments which have been made in Switzerland with mixtures of acetylene and coal gas; the object being the replacement of the usual mixture of 67 per cent. of oil gas with 33 per cent. of acetylene. It has been found that a mixture of coal gas and acetylene in equal proportions gives the same illuminating power as the oil gas combination. The experiments have further shown that this mixture of gases may be put under a pressure of 9 atmospheres, and heated up to 100° C. without danger.

**Gun Powder in Machine Shops.** ANON. (*DuPont News Service.*)—A somewhat novel idea is in successful operation in the machine shops of the Delaware and Hudson Railroad Company at Watervliet, N. Y. They are using ordinary black sporting powder to save the time of mechanics for the following operations: Blowing nuts and bolts; breaking up iron and steel to be scrapped; forcing a locomotive piston when rust or corrosion binds it; breaking metal that has become cold in a furnace.

The charge of powder is loaded in steel guns varying in size from end to end from 5 to 12 inches with other dimensions in proportion, and held by a steel plunger, which is forced out when the charge is set off. No wad is used. The plunger is milled to a size to fit the bore of the gun. Some of the gun-barrels are milled in the shape of an octagonal prism, instead of being cylindrical, the bore, of course, in all cases being round. The gun after having been loaded is jacked up with the mouth within about one inch of the object to be struck by the plunger and fired. An average of one ounce of powder is used for each nut or bolt (sizes in common use on locomotives) that is to be broken off or loosened. The load, of course, is varied with the work to be done. By the use of these guns, it is claimed much time and labor can be saved and that a quick blow can be directed at an object that is barely reachable otherwise.

## NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

### CHEMICAL ANALYSES OF LOGAN BLACKBERRY (LOGANBERRY) JUICES.[1]

By R. S. Hollingshead.

[ABSTRACT.]

The Bureau of Chemistry recently completed an investigation, undertaken to establish methods for the detection of dilution common in commercial products made from the Logan blackberry, and to set analytical standards for them. Logan blackberry juice has become very popuplar as a beverage, and the berry is used also in making jams, jellies, and soda-fountain sirups. The juice is naturally so sour that when it is to be used as a beverage it must be diluted, from 2 to 3 parts of water being the usual proportion, and sweetened with sugar, about 1 part. As a rule, sirups for the soda-fountain are prepared by adding sugar to the undiluted juices, in the proportion of from about 1 part of juice to 1 part of sugar to, roughly, 3 parts of juice to 1 of sugar.

Many samples of the pure expressed juice and of the commercial product made from berries grown in Washington and Oregon were analyzed by the Bureau in 1916, while in 1917 a large number of samples made from California berries were examined.

The juices from the fruit grown in Washington and Oregon were found to differ markedly in composition from those which came from the California berries. A large variation was also noted in the composition of juices from fruit grown in the different parts of these States, due probably to the difference in rainfall. Apparently California juices have a somewhat higher ash content and lower acid content than those from the more northern States.

It would seem impossible to determine exactly the amount of water which has been added to commercial Logan blackberry juices. Its presence can, however, be detected, and the amount roughly approximated. The following table gives the tentative limits suggested for the most significant determinations on Logan blackberry products.

* Communicated by the Chief of the Bureau.

[1] Department of Agriculture Bulletin 773, issued May 29, 1919.

*Tentative Limits for Logan Blackberry Juices.*

| Source | Non-sugar solids | | Ash | | Acids, as citric | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Washington and Oregon .... | 3.92 | 2.80 | 0.43 | 0.25 | 2.33 | 1.42 |
| California .................. | 3.74 | 3.06 | .63 | .43 | 1.96 | 1.06 |

## AN AËROBIC, SPORE-FORMING BACILLUS IN CANNED SALMON.[2]

By Albert C. Hunter and Charles Thom.

[ABSTRACT.]

Bacteriological examination of 530 cans of salmon, representing 9 different brands, showed 237 unsterile cans, 224 of which contained a particular organism of the mesentericus group, either in pure culture or mixed with other species. Only 13 of the cans showed active spoilage.

The organism is an obligate aërobic spore-former, Gram positive, and motile. It produces a dark-red ring about a centimeter below the colony in carbohydrate media and causes rapid decomposition in fish.

No relation exists between the presence of bacteria of this type and the quality of the food when the can is opened. The fish in many cans containing the organisms appeared to be perfectly fresh and sound, while in some sterile cans the fish was obviously decomposed.

A bacteriological test for sterility in canned food may show viable organisms without demonstrating spoilage. The purpose of canning is accomplished if the food is preserved but the finding of viable organisms calls for close scrutiny both of the material and of the canning method used.

## ZINC IN OYSTERS.[3]

By R. S. Hiltner and H. J. Wichmann.

[ABSTRACT.]

In 1915 notable amounts of zinc in oysters were found almost simultaneously in two of the laboratories of the Bureau of Chemistry, each working independently of the other and on quite dif-

[2] *J. Ind. Eng. Chem.*, Vol. xi, No. 7 (July, 1919).

[3] *J. Biol. Chem.*, vol. xxxviii, No. 2 (June, 1919).

ferent problems. The Bureau, therefore, undertook an investigation of the occurrence of zinc and also of copper in oysters from various localities on the Atlantic seaboard. The relation of the zinc content of the water in which the oysters grew to that of the oysters, and the ratio of zinc to copper in oysters, were studied also.

The results of this investigation indicated that zinc is universally present in oysters, at least in those grown in Atlantic waters, and that it is probably always associated with copper. It was also evident that no direct relation exists between the zinc content and the body weight of the oysters, no uniformity in the ratio of zinc to copper, and no correlation between the zinc content of the oysters and that of the water in which they grow. The average zinc content of 60 samples of oysters analyzed was found to be 457 milligrams per kilogram, the values ranging from 26 to 1300. The quantities of copper found in 29 samples ran from 12 to 362, with an average of 80 milligrams per kilogram. The greater amounts were found in water contaminated by metallurgical and factory wastes. Vegetation and organic matter dredged up with the oysters in one locality contained notable quantities of zinc, and in some instances traces of copper.

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## COMMERCIAL PRESERVATION OF EGGS BY COLD STORAGE.[4]

By M. K. Jenkins.

[ABSTRACT.]

AN extensive investigation on the preservation of eggs by cold storage was conducted during the seasons of 1914, 1915, and 1916. The contents of 841 cases were examined on going in and again on coming out of storage. That is, approximately 26,000 eggs were examined individually, each egg being candled twice. Most of the eggs used in the observations recorded were purchased in the Corn Belt States of the Middle West, and were shipped east in refrigerator cars, being from 3 to 7 days *en route*. As soon as received they were transferred to a commission house equipped with chill rooms, a candling and a breaking room, all of which were refrigerated. Here numerous observations were made of the eggs before being stored and at various intervals during the storage period.

[4] U. S. Department of Agriculture Bulletin 775, issued June 3, 1919.

Candling proved to be a much more accurate method for the selection of eggs than inspection or clicking.

Freshly laid eggs, with clean whole shells that had not been wet, showed a negligible loss in bad eggs, even after they had been stored 10 or 11 months.

The rate of evaporation of moisture from eggs was remarkably uniform during the storage period, and averaged from 3 to 4 ounces per case per month in the storage rooms under observation. This moisture was condensed on the brine pipes and absorbed by the air, the case and the fillers. Most of the absorption of moisture by the egg packages occurred during the first few months in storage. A gradual rise in the humidity of the cold storage room was noted with the advance of the season.

Eggs which were fresh when stored showed, after being held some time, an increased air space, and often a tinge of yellow in the white. Although the yolk membrane became slightly weakened, commercial separation into white and yolk usually was easily accomplished, even after eleven months' storage. The percentage of ammoniacal nitrogen in eggs increased during storage, the rise being greatest during the early part of the storage period.

While held commercially in cold storage eggs develop a characteristic "cold storage" taste, which usually can be detected about the seventh month in storage, and grows stronger the longer the eggs are held thereafter. This flavor probably is due to the absorption of the odors from the surroundings, particularly the strawboard fillers in which the eggs are packed.

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**Hydroelectric Power for West Coast of Africa.** ANON. (*Electrical Review,* vol. lxxiv, No. 24, p. 981, June 14, 1919.)—A hydroelectric plant is being built by the Bauchi Tin Mines, Northern Nigeria, which will be used to operate the tin mines. This hydroelectric development will have an initial capacity of 1500 horse power, which will be transmitted 12 miles to the mines. The cost of the installation will be in the neighborhood of $400,000. It is estimated that the cost of energy will be about 1.2 cents per kilowatt-hour as compared to 5.2 cents for energy generated from coal or oil. The annual saving which it is estimated will result from this change is $195,000.

## NOTES FROM THE U. S. BUREAU OF MINES.*

### MOTOR GASOLINE; PROPERTIES, LABORATORY METHODS OF TESTING, AND PRACTICAL SPECIFICATIONS.[1]

By E. W. Dean.

Gasoline as bought on the market may be the product of ordinary refinery distillation, it may be casing-head gasoline blended with heavy naphtha, or it may be the product of a cracking process. These three may be blended with each other in varying proportions. The volatility desirable depends on the service required and on the vaporizing power of the engine. In general, there should be enough loco-boiling constituents to permit the ready starting of a cold motor and not enough to make the gasoline dangerous and subject to high evaporation losses. Within the capacity of the engine to utilize them efficiently the heavier and less volatile fractions have a greater horsepower per gallon. Proposed specifications for gasoline are given, analytical methods and equipment used in connection with them are described.

### TRAPS FOR SAVING GAS AT OIL WELLS.[2]

By W. R. Hamilton.

An oil well that does not produce appreciable quantities of gas along with the oil, especially during its early life, is an exception. When wells flow freely into the air a serious loss of oil results. The loss is from two causes: (1) The sudden release of pressure which allows the gas to escape and carry with it quantities of oil which are held in suspension; and (2) the evaporation caused by the spray of oil. The loss from evaporation alone in a wildly flowing well producing oil of Cushing grade, will probably exceed 25 per cent. during the time of expulsion. This does not cover losses in handling and storage. The gas is of course wasted. Not only do the so-called dry gases escape, but they carry away much of the lighter oil fractions as vapor, so that the escaping gas is often highly saturated with gasoline, causing a heavy loss.

* Communicated by the Director.

[1] Technical Paper No. 214.

[2] Technical Paper 209.

Gasoline traps are simple in construction. The mixture of oil and gas is allowed to flow through a chamber large enough to reduce the velocity of the mixture to the point where the oil and gas tend to separate. The gas is drawn off from the oil at the top of the chamber. The oil is drawn off at a point below the level of the liquid so that the escape of gas through the discharge opening is prevented. In this way all the gas is saved and its gasoline content may be recovered and the evaporation of the oil is prevented. In addition, the danger of the well catching fire is greatly reduced. Different designs of traps are described, some one of which will be suited to the conditions existing in any given well. The small cost of a trap and the large savings which result from its use make it desirable that they should be used in all cases. It would, in fact, be desirable that their use should be made compulsory by State legislation.

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## LIGNITE: ITS CHARACTERISTICS AND UTILIZATION.[3]

By S. M. Darling.

ONE-THIRD of the known coal resources of the United States consists of lignite, which is little used because it normally contains 35–30 per cent. of water as mined, but loses it by evaporation on exposure, with the result that it crumbles into fine pieces during shipment. The freight rate on the contained water is also important. As a result 2,000,000 tons of bituminous coal, hauled on the average 1000 miles, is shipped annually into territory tributary to the North Dakota lignites that could be supplied with lignite with an average haul of 400 miles; saving annually the travel for 600 miles of 50,000 coal cars and 1200 engines and train crews. The same general condition obtains in the territory tributary to the Texas lignites. Dried lignite may be used on automatic stokers, pulverized lignite may be used in that form, dried lignite briquettes may be used in hand-fired furnaces, carbonized lignite may be used in suction power-gas producers, and carbonized lignite briquettes may be used for industrial heating. Raw lignite used in by-product gas producers yields 60,000 to 70,000 cubic feet of gas of 140 B. T. U. per cubic foot; 70 to 80 pounds of sulphate of ammonia, and some tar, of undetermined value. The experiments so far conducted open wide economic and commercial possi-

[3] Technical Paper 178.

bilities, and it is believed that the broader and more thorough investigation made possible by the recent appropriation of $100,-000 for investigation by the Bureau of Mines will point the way to the establishment of carbonizing and briquette plants throughout the lignite-bearing regions of the country. The present yearly production of coal amounts to 0.017 per cent. of the known minable coal resources of the country. C. P. Steinmetz is authority for the statement that the possible hydro-electric power that could be developed if every drop of water in the whole United States could be used would not supply an equal amount of power. It is evident, therefore, that the efficient utilization of our lignite resources is a problem of the first magnitude.

## MINOR NOTES.

*T. N. T.*—An investigation of the hygroscopicity of T. N. T., recently completed at the Pittsburgh Station of the Bureau of Mines, shows that it is no greater than that of an empty crucible or one filled with powdered glass; that the moisture absorbed in a saturated atmosphere is merely that due to the usual moisture deposited on non-hygroscopic substances under these conditions. The detailed results of this study will soon be published.

*Waste Products of Kaolin.*—It has been found by the Columbus Station of the Bureau that the waste products from the refining of kaolins can be used in some cases for the making of high-grade silica fire-brick. Where the brick are highly colored with iron, a 2 per cent. solution of $CaCl_2$ is used and the chlorine liberated removes most of the iron by volatilization. Dolomite brick were successfully made by mixing 12 per cent. coal tar with dead-burned dolomite, pressing at 1000 pound per square inch and burning to cone 20. In order to make brick more resistant to slaking, dipping in dehydrated tar was found to give the best results.

*Photometer.*—The construction of a photometer to measure the intensity of luminosity of dials or other surfaces covered with radium luminous material has been completed at the Golden, Colorado, station.

*Geophone.*—In a recent test with the geophone at coal mines in Pennsylvania, pounding with a sledge in the rib of a mine was detected through a cover of 525 feet.

*Volatilization Plant.*—The new volatilization plant at the Salt Lake City Station of the Bureau consists of a rotary kiln with a

capacity of 300 pounds ore per hour and a Cottrell precipitation plant with a capacity of 3000 cubic feet of gas per minute. The kiln has a length of 20 feet and is heated with a high-pressure burner, burning gas oil of 25° B., and is driven by an electric motor so arranged that the speed of rotation may be varied. The Cottrell precipitator consists of two units of twenty 6-inch pipes each. It is operated by a Thoradson 5 KVa. 80,000-volt precipitator transformer and a Western Precipitation Company rectifier. The regulation of the primary voltage of the transformer is obtained by an auto transformer and a theatre dimmer.

*Mine Fires.*—At the mine of the Princeton Coal Company, Indiana, an area which had been sealed off to extinguish a fire was recovered with the coöperation of the Bureau engineers, at the end of April.

*Alaska Power Development.*—A study of the possibilities of power development in the interior of Alaska has been made by the Fairbanks Station, which indicates that the present demand for coal for domestic heating, steaming purposes, and for electric power for placer and lode mining and domestic use would justify the erection of a plant to utilize the Nenana lignite. A carbonization plant would furnish the solid fuel required and yield enough gas to generate part of the power required. The remainder would be generated by a steam plant burning carbonized or dead lignite. To the present time the demand for fuel has been met with wood, but the growing scarcity and increasing cost of it make it essential that some other form of power supply be made available, otherwise the mining and other industries of the region will inevitably suffer a progressive decline.

*Silver Chloride.*—An investigation of the vapor pressure of silver chloride is in progress at the Berkley station of the Bureau. The method is not yet sufficiently standardized to yield thoroughly reliable results, but the work so far indicates that the vapor pressure of silver chloride is less than 5 mm. at 1000° C. and in the vicinity of 15 mm. at 1150° C. It is therefore much less volatile than lead chloride.

*Mine Gases.*—An extensive series of gas samples were taken at the recent fire in the Argonaut Mine, California, and it was found that the systematic analysis of gases from the main ventilation shaft served as a reliable index of conditions in the fire zone.

# THE FRANKLIN INSTITUTE.

## COMMITTEE ON SCIENCE AND THE ARTS.

*(Abstract of Proceedings of the Stated Meeting held Wednesday, June 4, 1919.)*

Hall of The Franklin Institute,
Philadelphia, June 4, 1919.

Mr. Benjamin Franklin *in the Chair.*

The following report was presented for final action:

No. 2729: Simplex Fluid Meter. A quorum not being present, final action was deferred.

R. B. Owens,
*Secretary.*

## MEMBERSHIP NOTES.

### ELECTIONS TO MEMBERSHIP.

*(Stated Meeting, Board of Managers, June 11, 1919.)*

RESIDENT.

Mr. Walter B. Murphy, Manufacturing Manager, The Barrett Company, Chemical Department, Frankford, Philadelphia, Pennsylvania.

NON-RESIDENT.

Dr. E. A. Eckhardt, Physicist, Bureau of Standards, Washington, District of Columbia.

Mr. Francis P. Fleming, Attorney-at-Law, Heard Building, Jacksonville, Florida.

### CHANGES OF ADDRESS.

Mr. G. Edward Barnhart, 318 Mills Avenue, Akron, Ohio.

Mr. William E. Bullock, 29 West 39th Street, New York City, New York.

Mr. Thomas L. Burton, Westinghouse Air Brake Company, 165 Broadway, New York City, New York.

Mr. Edwin M. Chance, 611 Chestnut Street, Philadelphia, Pennsylvania.

Mr. Frank H. Clark, 15 Park Row, New York City, New York.

Lieutenant Colonel George S. Crampton, M. C., U. S. A., Office of the Surgeon, District of Paris, No. 7, Rue Tilsitt, Paris, France.

Mr. J. H. Granbery, care of Morgan, Harjes & Company, 14 Place Vendome, Paris, France.

Mr. William A. Haines, 6445 Wissahickon Avenue, Philadelphia, Pennsylvania.

Mr. H. A. Hornor, Minerva P. O., Essex County, New York.

Miss Emily E. Howson, Glen Moore, Chester County, Pennsylvania.

Mr. Edwin F. Kingsbury, Eastman Kodak Company, Rochester, New York.

Mr. Clinton N. Laird, Canton Christian College, Canton, China.

Dr. Hugo Lieber, 23 East 26th Street, New York City, New York.

Mr. J. Milliken, Union Arcade Building, Pittsburgh, Pennsylvania.

MR. HUGH RODMAN, Rodman Chemical Company, Verona, Pennsylvania.
MR. JAMES G. VAIL, Philadelphia Quartz Company, 121 South 3d Street, Philadelphia, Pennsylvania.
MR. FRANCIS RALSTON WELCH, Devon, Pennsylvania.
MR. ALAN WOOD, 3d, Flat Rock, North Carolina.
MAJOR ARTHUR W. YALE, 1947 Linwood Avenue, San Diego, California.

## NECROLOGY.

**Mr. C. W. Allen,** 523 Oley Street, Reading, Pennsylvania.
**Mr. Charles O. Baird,** 207 Crozer Building, Philadelphia, Pennsylvania.
**Miss Harriet Blanchard,** 1511 Walnut Street, Philadelphia, Pennsylvania.

## LIBRARY NOTES.

### PURCHASES.

CARNEGIE, DAVID, and GLADWYN, S. C.—Liquid Steel, Its Manufacture and Cost. 1918.
Chemical Society of London.—Annual Reports on the Progress of Chemistry. Vol. 15. 1918.
CROWTHER, J. A.—Life and Discoveries of Michael Faraday. 1918.
ETCHELLS, E. F.—Mnemonic Notation for Engineering Formulæ. 1918.
FINDLAY, ALEXANDER.—Osmotic Pressure. 1919.
HARGER, W. G., and BONNEY, E. A.—Handbook for Highway Engineers. 1919.
KINNICUTT, L. P., Winslow, C. E. A., and PRATT, R. W.—Sewage Disposal. 1919.
LEWIS, W. C. McC.—A System of Physical Chemistry. 3 vols. 1918.
MACROBERT, T. M.—Functions of a Complex Variable. 1917.
MILLER, B. L., and SINGEWALD, J. T.—Mineral Deposits of South America. 1919.
ROSS, JOSEPH.—Waterproofing Engineering. 1919.
WASHINGTON, H. S.—Manual of the Chemical Analysis of Rocks. 1919.

### GIFTS.

Academia das Sciencias de Lisboa, Boletim da Segunda Classe, Vol. xi, Fasiculo Nos. 1 and 2; Historia e Memorias da Academia, Novo Serie, Tomo xii, part ii; Journal de Sciencias Matematicas, Fisicas e Naturais, Terceira Serie, Tomo i, Numeros 3 and 4; Depois do Terremoto, por. G. de Matos Sequeira, Vol. ii; Relacao da Embaixada a Franca em 1641, por Joao Franco Barreto; Sessao Publica, 2 de Junho de 1918; Arsenicais e Sifilis Critica do Tratamento Abortivo, por Thomaz de Mello Breyner; Lord Byron's Childe Harold's Pilgrimages to Portugal critically examined by D. G. Dalgado. Lisboa and Coimbra, 1917–1919. (From the Academy.)
Alberger Pump and Condenser Company, Bulletin No. 29. New York, N. Y., no date. From the Company.)
American Society of Mechanical Engineers, Year Book, 1919. New York, N. Y., 1919. (From the Society.)

American Steam Conveyor Corporation, Catalog on Reducing Ash Disposal Costs. New York, N. Y., 1919. (From the Corporation.)

Amherst College, Catalog 1918–1919, and Report of the President to the Trustees. Amherst, Mass., 1918. (From the College.)

Archdale, James & Son, Catalog of Drilling Machines. Birmingham, England, 1918. (From the Company.)

Association Française Pour l'Avancement des Sciences, Conferences, 1917–1918. Paris, 1918. (From the Association.)

Badenhausen Company, Bulletin No. 101. Philadelphia, Pa., 1919. (From the Company.)

Bangor Public Library, Annual Report 1918. Bangor, Pa., 1919. (From the Library.)

Bettcher Stamping and Manufacturing Company, Catalog of Flat Split Keys. Cleveland, O., no date. (From the Company.)

Biehl Iron Works, Inc., Catalog No. 8. Reading, Pa., 1919. (From the Company.)

Boston and Maine Railroad, Annual Report 1918. Boston, Mass., 1919. (From the Company.)

Brady, James A., Foundry Company, Bulletin No. 3. Chicago, Ill., 1919. (From the Company.)

Bridgeport Safety Emery Wheel Company, Inc., Catalog C, Grinding Wheels and Machinery. Bridgeport, Conn., no date. (From the Company.)

Buckeye Twist Drill Company, Catalog No. 6. Alliance, O., no date. (From the Company.)

Budd Grate Company, Catalog on Boiler Furnace Operation. Philadelphia, Pa., no date. (From the Company.)

Buffalo, Rochester and Pittsburgh Railway Company, Thirty-fourth Annual Report, for the year ending 1918. Rochester, no date. (From the Company.)

California Board of State Harbor Commissioners, Biennial Report for the Year Commencing July 1, 1916, and Ending June 30, 1918. San Francisco, 1919. (From the Board.)

Camden Forge Company, Catalog of Forgings. Camden, N. J., 1919. (From the Company.)

Canada Department of Trade and Commerce, Report Relating to Mail Subsidies and Steamship Subventions, 1918. Ottawa, 1919. (From the Department.)

Catholic University of America, Year Book, 1919–1920. Washington, D. C., 1919. (From the University.)

Chain Belt Company, Catalogs Nos. 95, 101 to 105. Milwaukee, Wis., 1919. (From the Company.)

Champion Engineering Company, Bulletin No. 106. Kenton, O. (From the Company.)

Columbian Bronze Corporation, Book: Propellers in a Nut Shell. New York, N. Y., 1919. (From the Corporation.)

Concord, N. H., Board of Water Commissioners, Annual Report, 1918. Concord, 1919. (From the Board.)

Cutler-Hammer Manufacturing Company, Catalog on C-H Wiring Devices. Milwaukee, Wis., 1918. (From the Company.)

Dartmouth College, Catalog, 1918–1919. Hanover, N. H., 1918. (From the College.)

Defender Automatic Regulator Company, Catalog No. 11. St. Louis, Mo., 1918. (From the Company.)

Denison University, Annual Catalog, 1918–1919. Granville, O., 1919. (From the University.)

Direct Separator Company, Catalog No. 19. Syracuse, N. Y., no date. (From the Company.)

Dubilier Condenser Company, Inc., A Record of the Invention, Development and Uses of the Dubilier Mica Condenser. New York, 1919. (From the Company.)

Duntley-Dayton Company, Bulletin No. 101. Philadelphia, Pa., 1919. (From the Company.)

Electric Hoist Manufacturers' Association: The Strong Arm of Industry. New York, N. Y., 1919. (From the Association.)

Electric Machinery Company, Bulletin No. 501. Minneapolis, Minn., no date. (From the Company.)

Electric Tachometer Company, Bulletin No. 111. Philadelphia, Pa., no date. (From the Company.)

Flory, S., Manufacturing Company, Catalog No. 26. Bangor, Pa., 1919. (From the Company.)

Gold Car Heating and Lighting Company, Catalogs of Heating and Ventilating Apparatus for Railway Cars. New York, N. Y., no date. (From the Company.)

Grand Trunk Railway Company of Canada, Report of the Directors and Statements of Accounts, 1918. Montreal, Canada, 1919. (From the Company.)

Grafton and Knight Manufacturing Company, Catalog No. 7. Worcester, Mass., 1919. (From the Company.)

Green Engineering Company, Catalog: The Green Book. East Chicago, Ind., 1919. (From the Company.)

Green Fuel Economizer Company, Bulletin No. 151. Beacon, N. Y., 1919. (From the Company.)

Guaranty Trust Company, Publications: How Business with Foreign Countries is Financed; Trading with China; Canada Economic Position and Plans for Development. New York, N. Y., 1919. (From the Company.)

Haverford College, Catalogs 1917–1918 and 1918–1919. Haverford, Pa., 1919. (From the College.)

Hollands Manufacturing Company, Catalog No. 24. Erie, Pa., no date. (From the Company.)

Illinois Steel Company, Catalog of Track Materials. Chicago, Ill., 1919. (From the Company.)

Ingersoll-Rand Company, Bulletins of Air Compressors, Vacuum Pumps, Steam Engines, etc. New York, N. Y., 1918–1919. (From the Company.)

Jeffrey Manufacturing Company, Catalog No. 210. Columbus, O., 1919. (From the Company.)

Jointless Fire Brick Company, Catalog of Jointless Fire Brick. Chicago, Ill., 1919. (From the Company.)

Keller Pneumatic Tool Company, Catalog. Chicago, Ill., no date. (From the Company.)
Koehring Machine Company, Blue Print Suggestions on Haulage; Loading Stations and Mixer Equipment for Road Work. Milwaukee, Wis., 1919. (From the Company.)
Landis Machine Company, Catalog No. 25. Waynesboro, Pa., 1919. (From the Company.)
Lawrence Pump and Engine Company, Catalog "C." Lawrence, Mass., no date. (From the Company.)
Leland Stanford Junior University, Annual Report of the President. Stanford University, California, 1918. (From the University.)
Lincoln Twist Drill Company, Catalogs No. 10 and 10C. Taunton, Mass., 1918. (From the Company.)
Locomotive Superheater Company, Bulletin No. T 1. New York, N. Y., 1919. (From the Company.)
Long and Allstatter Company, Catalog of McClave Grates and Argand Blowers. Scranton, Pa., 1916. (From the Company.)
Maple Flooring Manufacturers' Association, Catalog. Chicago, Ill., 1919. (From the Association.)
Mill Corporation, Catalog No. G-1: Laboratory Glassware. Rochester, N. Y., 1919. (From the Corporation.)
Minnesota Railroad and Warehouse Commission, Annual Report, 1918. St. Paul, Minn., 1918. (From the Commission.)
Moore and White Company, Catalog of Friction Clutches. Philadelphia, Pa., 1915. (From the Company.)
Nash Engineering Company, Bulletins Nos. 7 and 8. South Norwalk, Conn., 1918. (From the Company.)
National Transit Pump and Machine Company, Bulletins and Special Bulletin. Oil City, Pa., 1919. (From the Company.)
New Bedford Board of Health, Annual Report for the Year 1918. New Bedford, Mass., 1919. (From the Board.)
New York State Engineer and Surveyor, Annual Report, and Supplement, 1917. Albany, N. Y., 1918. (From the State Engineer and Surveyor.)
Norwalk Iron Works Company, Catalog on Air and Gas Compressors. South Norwalk, Conn., no date. (From the Company.)
Ohio Geological Survey, Bulletin No. 21. Columbus, O., 1918. (From the Survey.)
Page Steel and Wire Company, Booklet on Armco Iron Rods and Wire for Oxy-Acetylene and Electric Welding. New York, N. Y., 1919. (From the Company.)
Pacific Tank and Pipe Company, Catalog on Mining Tanks. San Francisco, Calif., no date. (From the Company.)
Packard Motor Car Company, Catalog of the Packard Liberty Motor. Detroit, Mich., 1919. (From the Company.)
Pennsylvania Railroad Company, Record of the Transportation Lines, 1918. Philadelphia, Pa., 1919. (From the Company.)
Pittsburgh Filter and Engineering Company, Bulletin O.E. 20. Kansas City, Mo., 1919. (From the Company.)

Potter, S. A., Tool and Machine Works, Catalog No. 9. New York, N. Y., 1919. (From the Company.)

Rockwell, W. S., Company, Bulletin No. 39. New York, N. Y., 1919. (From the Company.)

Rose Polytechnic Institute, Bulletin 1918–1919. Terre Haute, Ind., 1919. (From the Institute.)

Schieren, Charles A., Company, Catalog: The Story of Schieren Beltings. New York, N. Y., 1919. (From the Company.)

Sheffield Machine and Tool Company, Sheffield Tools and Products. Dayton, O., 1919. (From the Company.)

S. K. F. Ball Bearing Company, Engineers' Ball Bearing Handbook; and booklet: The Present Day Application of Ball Bearings. Hartford, Conn., 1918. (From the Company.)

Smithsonian Institution, Annual Report of the U. S. National Museum, 1918. Washington, D. C. (From the Institution.)

Springfield, Mass., Board of Water Commissioners, Annual Report, 1918. Springfield, 1919. (From the Board.)

Standard Spiral Pipe Works, Catalog No. 7. Chicago, Ill., no date. (From the Company.)

Steere Engineering Company, Bulletins Nos. 34, 35 and 37. Detroit, Mich. (From the Company.)

Sturtevant, B. F., Company, Catalogs Nos. 255 and 256. Boston, Mass., 1919. (From the Company.)

Tasmania Department of Mines, Geological Survey, Bulletin No. 28. Hobart, 1918. (From the Department.)

Terry, Edward F., Manufacturing Company, Catalog of Derricks and Cranes. New York, N. Y., no date. (From the Company.)

Thermoid Rubber Company, Booklet: New Principles in Tire Making. Trenton, N. J., 1918. (From the Company.)

Tinus Olsen Testing Machine Company, Catalog No. 10, Part A. Philadelphia, Pa., 1919. (From the Company.)

Tokyo Imperial University, Calendar, 1917–1918. Tokyo, Japan, no date. (From the University.)

University of Denver, Year Book. Denver, Col., 1919. (From the University.)

University of Florida, Catalog, 1918–1919; Announcements, 1919–1920. Gainesville, Fla., 1919. (From the University.)

University of Nevada, Biennial Report of the Regents, 1917–1918. Reno, Nev., 1919. (From the University.)

University of Rochester, Annual Catalog, 1918–1919. Rochester, N. Y., 1919. (From the University.)

University of the State of New York, Library Report, 1917. Albany, N. Y., 1918. (From the University.)

Ursinus College, Bulletin, 1918–1919, First Quarter. Collegeville, Pa., 1919. (From the College.)

Uruguay Anuario Estadistico, Año 1916, Libro xxvi. Montevideo, 1918. (From the Director General de Estadistica.)

Washington University, Annual Catalog, 1918. St. Louis, Mo., 1918. (From the University.)

Wellman-Seaver-Morgan Company, Bulletins, Circulars and Catalogs on Hydraulic Turbines, Ore and Coal Handling Machinery, and Buckets. Cleveland, O., no date. (From the Company.)

Wheeler Condenser and Engineering Company, Bulletin No. 113. Carteret, N. J., 1919. (From the Company.)

Winfield Electric Welding Company, Catalog of Electric Welding. Warren, O., 1917. (From the Company.)

Winter Brothers Company, Catalog No. 13. Wrentham, Mass., 1918. (From the Company.)

Yale and Towne Manufacturing Company, Semi-Centennial Souvenir. New York, N. Y., 1918. (From the Company.)

## CORRESPONDENCE.

*Cable Address "Edison, New York"*

FROM THE LABORATORY OF THOMAS A. EDISON.

ORANGE, N. J. April 19, 1919.

*Mr. R. B. Owens, Secretary,*
*The Franklin Institute,*
*Philadelphia, Penna.*

DEAR SIR:

I thank you for your letter of April 17th, and wish to express my sincere appreciation of the honour conferred upon me by The Franklin Institute in electing me an Honorary Member of the Institute.

Yours very truly,
(Signed) THOS. A. EDISON.

A/6969.

WAR DEPARTMENT
OFFICE OF THE CHIEF SIGNAL OFFICER

WASHINGTON, April 23, 1919.

*Major R. B. Owens,*
*Secretary, The Franklin Institute,*
*Philadelphia, Pa.*

SIR:

I have the honour to acknowledge receipt of your communication of April 17, 1919, informing me that at a Stated Meeting of the Institute held on the evening of Wednesday, April 16, 1919, I was unanimously elected an Honorary Member of The Franklin Institute.

I beg to express to the Institute, through you, my sincere appreciation of its action in thus electing me an Honorary Member of the oldest scientific institution in America, one which has through all the years exerted a powerful influence in the advancement of Science and the Mechanic Arts.

Faithfully yours,
(Signed) GEORGE O. SQUIER.
*Major General*
*Chief Signal Officer of the Army.*

WOLCOTT GIBBS MEMORIAL LABORATORY, HARVARD UNIVERSITY.

CAMBRIDGE, MASSACHUSETTS, U. S. A., April 24, 1919.

THEODORE WILLIAM RICHARDS, *Director.*

*Dr. R. B. Owens,*
*Secretary,*
*The Franklin Institute of Pennsylvania.*

SIR:

Your letter of April 17th honours me very greatly. I beg that you will communicate to the Members of the Institute my heartfelt appreciation of the high distinction conferred upon me by election to honorary membership. It is an especial pleasure and satisfaction that the eminent men of my native State and City should thus welcome me to their fellowship; and I shall always be proud indeed to have my name entered on the rolls of the famous Institute.

I beg to remain, with assurances of highest regard

Respectfully yours.
(Signed) THEODORE W. RICHARDS.

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HENRY C. FRICK EDUCATIONAL COMMISSION.
1954 Perrysville Avenue.

JOHN A. BRASHEAR, *President.*

PITTSBURGH, Pa., May 16, 1919.

MY DEAR DR. OWENS,

You don't know how proud I am of the beautiful diploma of Honorary Membership of The Franklin Institute. There are eleven diplomas hanging on the walls of my work room and all so nice and fully appreciated, but the Franklin is the prettiest of all.

Then an old fellow like me prizes the names on his diplomas—especially if they happen to be his friends—and all the names are friends of Uncle John. I confess that I am in love with this diploma and the honor you have conferred upon me. The good Lord knows the element of self conceit has never tainted the life of your friend—but when I unrolled the diploma—or rather had my granddaughter do it for me, I felt just a pardonable pride! So don't scold me for this little weakness, for though nearly 79, I am not in my dotage yet. A fellow working 12 to 14 hours a day trying to send a little sunlight out into the world to make or help make the shadowed pathways of his fellow travellers a little brighter should not be accused of dotage, should he?

How I would love to be with you on the 21st. Sir James Dewar has been a personal friend for 27 years and General Squier a man for whom we have done some of our best work. I fear I cannot get away.

Thanking you dear Dr. Owens and all your colleagues, I am,

Cordially yours,
(Signed) JOHN A. BRASHEAR.

PROF. DR. H. KAMERLINGH ONNES.

LEIDEN, 24 May, 1919.
HUIZE TER WETERING
HAAGWEG.

SIR:

I beg to express my sincere gratitude for the honour The Franklin Institute has bestowed on me by electing me unanimously as an Honorary Member. The appreciation in this way of my work by The Franklin Institute who did me the honour to award one of the first Franklin Medals to me, makes a deep impression on me. I cannot thank The Franklin Institute enough for the continued encouragement given to me, but I can assure The Franklin Institute that this encouragement is of the greatest value for me now I am restarting my researches which have suffered very much from the general circumstances as well as from a long illness.

I am respectfully,
(Signed) H. KAMERLINGH ONNES.

DR. R. B. OWENS, *Secretary of The Franklin Institute of the State of Pennsylvania, Philadelphia.*

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31 Via Garibaldi, Gianicolo,
ROME, May 30th, 1919.

*R. B. Owens, Esq.,*
*Secretary of*
*The Franklin Institute,*
*Philadelphia, Pa.*

SIR,

Having been away from Italy for some time I have only just received your letter of April 17 in which you inform me that at a Stated Meeting of the Institute held on April 16 of this year I was elected Honorary Member.

I take great pleasure in accepting this Honorary Membership of The Franklin Institute, and shall feel obliged if you will convey to the Governors of the Institute my deep appreciation of the honor which they have conferred upon me.

I am,
Respectfully,
(Signed) G. MARCONI.

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HAARLEM, June 8, 1919.

GENTLEMEN:

Allow me to express my most hearty thanks for the honour you have bestowed upon me by electing me an honorary member. I appreciate very much this new token of the good will with which you have judged my work, and I consider the membership of your celebrated and time-honoured Institute as one of the very best rewards that can be given to a scientific man.

With high regards, I have the honour to be, gentlemen,

Your obedient servant,
(Signed) H. A. LORENTZ.

TO THE MEMBERS OF
THE FRANKLIN INSTITUTE.

## PUBLICATIONS RECEIVED.

*The Blind, Their Condition and the Work Being Done for Them in the United States,* by Harry Best, Ph.D. 763 pages, 12mo. New York. The Macmillan Company, 1919. Price, $4.

*U. S. War Department, Annual Reports 1918:* 3 vols., illustrations, plates, maps, diagrams, 8vo. Washington, Government Printing Office, 1919.

*U. S. Bureau of Standards:* Circular No. 76. Aluminum and Its Light Alloys. 120 pages, illustrations, 8vo. Washington, Government Printing Office. Price, 20 cents.

*U. S. Coast and Geodetic Survey:* Terrestrial Magnetism. Results of Magnetic Observations Made by the United States Coast and Geodetic Survey in 1918, by Daniel L. Hazard, Chief, Division of Terrestrial Magnetism. 32 pages, 8vo. Washington, Government Printing Office, 1919.

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**A Proposed "Poison-Gas."**—The signing of the armistice brought suddenly to a close several terrible methods of offense that were just about ready to be employed by the allied and associated powers. These methods have been more or less made known to the public, and among them is an asphyxiating gas which promised to be a valuable one for war purposes, and for which American chemists had just about succeeded in perfecting the procedure for mass manufacture when hostilities were suspended. The account of the method of manufacture was given a short time ago in the *Journal of Industrial and Engineering Chemistry.* The substance is methyldichlorarsin, $CH_3AsCl_2$. The process of manufacture is quite elaborate, and, as far as the experiments went, the cost of the pure product was about $2.50 per pound. The operation did not reach the extended development that was attained by mustard gas or phosgene, but was still within what was termed the "Small-scale Manufacturing Section of the C. W. S.," when Messrs. Uhlinger, Clapp and Cook, who furnish the account from which this note is quoted, were released from duty in the matter.

The properties of the substance are not given, but from its close relation to the kakodyl series it is not difficult to guess at its general nature as an asphyxiator. H. L.

**Coal Production in Germany.** ANON. (*Power,* vol. xlix, No. 25, p. 998, June 24, 1919.)—The German War Commissary states that Germany's coal production is decreasing in all districts, because the pay is no longer based on the work done but has a minimum of 16 to 18 marks ($3.81 to $4.28, at normal exchange) per day. The present coal production in the Ruhr district is 9000 to 10,000 tons per day, compared with 34,000 tons in peace times and 24,000 tons during the war. In upper Silesia the daily output has been reduced to 2000 carloads, compared with 14,000 in peace times and 11,000 during the war.

# CURRENT TOPICS.

**Mapping from the Air.** Anon. (*U. S. Geological Survey Press Bulletin.* No. 410, June, 1919.)—Requests made to the United States Geological Survey, Department of the Interior, for information concerning the possibilities of photographic surveying from airplanes or other aircraft have recently become so numerous that it is deemed necessary to issue a statement on this subject. For two years the United States Geological Survey, which prepares and publishes more maps than any other organization in the world, has devoted much time and labor to the study of problems to be solved in photo-aerial surveying. The camera has long been used in surveys on the ground, and the Geological Survey has been making studies to determine the best methods of using it in aerial work. Before the war the panoramic camera was employed by the Geological Survey for mapping in Alaska, and it has been widely used for photographic surveying in Canada and in Europe. Aerial photographic surveying involves no new principles, yet it differs essentially from photographic surveying on the ground, for the line of view from a camera in a balloon or an airplane is vertical, not horizontal. A complete statement of the Geological Survey's investigations in photographic mapping from the air will later be prepared for publication.

The principal object in an aerial survey is to obtain on a horizontal plate or film a picture of the area below the camera. If the area is itself a plane the picture of it taken from an airplane on such a plate is a true map, but no apparatus has yet been devised that will maintain the plate in a truly horizontal position when the airplane is in motion; and as the earth's surface is almost nowhere plane the photograph must be corrected to obtain a map free from distortion. The nearest approach to an aerial map so far made is the so-called "mosaic map," which is really not a map at all but merely a patchwork of photographs. The pictures composing such a mosaic show distortions, due partly to the deviation of the plate from the horizontal position and partly to relief in the surface photographed, and these distortions render the picture useless for accurate map construction. Distorted photographs of an area that has been previously mapped can be laid down over a network of points whose positions are known, and by distributing the errors due to distortion a mosaic may be constructed that will present a good appearance. For correcting and revising older maps by the addition of culture, timber areas, new roads, and similar features, such mosaics have a distinct value, but they are worth little as material for use in constructing new maps.

It may be said that photographic mapping from aircraft is entirely practicable but that it has not yet been brought to the point where it can supersede ground surveying. The science of cartography will no doubt be greatly advanced when the aerial method is perfected, but fundamental problems remain to be solved, and this fact should be recognized and all possible energy should be devoted to the solution of those problems. It is hoped that solutions of the essential problems in photo-aerial surveying will soon be obtained, and that this method will be put to practical use in map-making.

**New Chemical Journals and a New Method in Chemical Journalism.** H. LEFFMANN. (*The Catalyst,* vol. iv, No. 5, May, 1919.)—Early in the year 1918 the Swiss Chemical Society decided to begin the issue of a journal to appear from six to eight times a year, and contain brief notes and formal memoirs in the three languages (French, Italian and German) used in the country. By this means the Society hopes to give to the world a synopsis of the labors of Swiss chemists. The preface of the first number is dated at Geneva, April 25, 1918. The rivalry of the three languages, of course, increased in bitterness by the events of the last four years, has been deftly avoided by the founders of the journal by putting the title in Latin, *Helvetica Chemica Acta.* The first number is standard octavo size, containing ninety-five pages of original matter, well printed on good paper. The prospectus is given in the three languages, but the preface is in French. Of the seven contributions, four are in German and three in French. They cover both pure and applied chemistry. Among the latter is a notable one on the occurrence of hydrogen selenid in rain-water and melted snow. Several issues have appeared, and the amount and quality of the contents have maintained the standard of the initial number.

The other newcomer is from France. It is the official journal of the newly-formed French society of industrial chemistry. The first number of the journal (*Chimie et Industrie*) is dated June 1, 1918, and it has been continued since as a monthly. It contains about one hundred pages well printed on good paper of about the area of the J. I. E. C. The matter of the journal is of very good quality, and covers the usual variety of original papers and abstracts of current literature, but a special feature deserves some notice. Each number contains a section on "Economic Organization," in which questions of education, teaching, professional apprenticeship, industrial hygiene, protection of childhood, anti-alcoholic and antituberculosis crusades can be treated with a breadth of view and interest that they deserve. This indicates a broader scope than is usual in chemical journals, and affords an inkling of the deep impression that socialism has made upon the educated classes of France, especially in professional circles.

Science and Industry. (*Machinery*, London, vol. xiv, No. 350, p. 321, June 12, 1919.)—A new viewpoint manifests itself in the interminable controversy upon the application of science to industry, with which is bound up the place that theoretical training must take in engineering education. The whole history of the conflict of opinion among educationalists and industrialists is that the former has continually and dogmatically laid it down that the practical man in the past has had little understanding of the value of science and has therefore failed to appreciate the place which it should play in industrial life. Generally speaking, the so-called practical man has accepted the doctrine that science and theoretical training must take a more prominent place, and he has left it largely to the educationalist to define that place. A change, however, appears to be coming over the attitude of the practical, or, shall we say, the business man, in this respect. The point of view is that whilst professors and teachers wish the industrial employer to have a greater faith in science, have they themselves as much enthusiasm and faith—and, be it added, knowledge of practical conditions—in industry? In other words, have the teachers the practical knowledge which enables them to teach science in such a way that it can be applied to the best advantage in industry? Hitherto our universities and technical colleges have placed rather too narrow a limit upon the meaning of science; there is something more than a science of things which needs to be taught those who are to take the leading places in industry, and it has been well pointed out that there are such things as the science of management—the application of psychology in management—the training of staff and the direction of salesmanship to which at present our universities and colleges are paying very little attention. We believe that the only organized effort of this nature is being made at the Manchester University, but this aspect of the application of science in education and in industry must play a larger part in the minds of those from whom we are expected to take the law as regards education. That can only come about through the medium of a greater practical knowledge on the part of the teachers. This, perhaps, raises important questions as to whether the remuneration offered to those who are expected to teach our young men is sufficient to attract the right kind of men. Anyway, experience has shown that the average man engaged in industry has not the time, and often not the ability, to undertake teaching. Therefore we shall have to continue to rely mainly upon theoretically trained men for the purpose, but steps must be taken to keep such men in close contact with the needs of industry before we can expect our university and college curricula to fit those needs.

**Moving Pictures in Science.** (*Engineering News-Record,* vol. lxxxii, No. 26, p. 1239, June 26, 1919.)—Motion-picture houses for some time have been showing pictures of what they call the "analysis of motion," in which well-known actions, such as figure skating, sprinting and baseball pitching, are reproduced on the screen at one-eighth the actual speed of the performer. Every element of motion in these pictures stands out with snapshot clearness. Grace hitherto unsuspected is revealed, and the methods by which results are achieved are understood as never before. This latter phase has decidedly an engineering application in the development of motion study and its consequent readjustment of production methods. No false or unnecessary movement can escape detection, but at the same time the sense of motion, lacking in a series of snapshots, is always present. An analogy may be found in the system used by Nathan C. Johnson in studying the setting of concrete. While the popular motion picture film slows down normally fast processes, Mr. Johnson's automatic camera speeds up the normally slow, so that one can, for instance, observe in a few minutes the physical and chemical phenomena of many days. Motion pictures have already had a marked influence on social conditions; may they not have a bright future in science?

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## ELECTRICAL TREATMENT OF SEWAGE: THE LANDRETH DIRECT OXIDATION PROCESS.*†

BY

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### I. INTRODUCTION.

The first mention of the use of electricity in the purification of sewage is contained in an English patent, No. 1499, issued to J. Chisholm in 1856, for a process of disinfecting and deodorizing by electric or galvanic agency noxious or infected matters, such as occur in cesspools or sewers. No successful application seems to have been made of this process or of a number of other similar processes patented between the years 1870 and 1886.

Among the best known of the electrical processes is that invented by Webster, and installed experimentally at Crossness, England, in 1889, to treat London sewage. In this process the raw sewage flowed, in contact with iron electrodes, through long

* Communicated by the Author.

† This paper embodies the results of an investigation of the Landreth Direct Oxidation Process by the Committee of Science and the Arts of The Franklin Institute.

[Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the Journal.]

troughs, each section of which was made of two, four or more longitudinal parts bolted together but insulated from each other. In the electrolysis cell a current density of 0.9 ampère maintained by an electromotive force of about 2 volts was employed. For the treatment of raw sewage it was estimated that 240 pounds of iron and 450 kilowatt hours of electrical energy would be consumed per million gallons. In this process most of the nascent oxygen liberated at the anode was consumed in oxidizing the iron of the electrode, and the oxide thus formed acted as a precipitating agent on the sludge of the sewage. The process, therefore, was mainly one of chemical precipitation by means of the oxide of iron formed by the action of the electric current.

Plants operating along the general lines of the Webster process are in use in Santa Monica, California, and in Oklahoma City, Oklahoma. While no careful studies have been reported from either of these plants, it is understood that, for a time at least, both gave satisfactory results so far as purification was concerned.

To a second type of so-called electrical process for the purification of sewage belong those in which nascent chlorine, liberated by the electrolysis of a chloride, acts as a disinfectant. A process of this kind was first developed by E. Hermite, in 1887. The sewage was mixed with chlorides of magnesium, calcium or sodium, and the liquid thus charged was passed in thin sheets or streams between electrodes. In a similar process invented by A. E. Wolff, a strong brine solution was electrolyzed, and the resulting chlorine and caustic soda were allowed to recombine in the form of sodium hypochlorite, the solution of this latter substance being used for purifying the sewage. In 1893, the sewage of about thirty dwellings at Brewster, N. Y., was treated by the addition of hypochlorite solution made in this way, under the direction of the Health Department of New York City.[1] For every million gallons of sewage treated, 1600 pounds of salt were used, and the plant required an electric current of 700 ampères at 5 volts. "This seems to have been the first plant established for the specific purpose of destroying bacteria. Before that time the removal of organic matter had been the aim."[2]

Extensive investigation has shown that electrical treatment of sewage is capable of practical use, but that the precipitants and disinfectants prepared by electrolysis will have the same efficiency

[1] *Eng. News*, 30, 41 (1893).

[2] *Water Supply Paper* No. 229, p. 27, U. S. Geol. Survey.

and no greater efficiency as when manufactured outside. As Kennicut, Winslow and Pratt point out,[3] "the important question is whether electrolysis in the presence of the sewage is or is not the most economical method of preparing and applying such precipitants and disinfectants as are needed. If the problem is regarded from this practical standpoint and without vague mystical conceptions of the purifying agency of electrical energy as such (which are apt to cloud the matter in the lay mind), a sound conclusion may be reached in any given case by a careful consideration of operating costs; and this conclusion will not generally be in favor of electric treatment."

The failure of sedimentation to clarify sewage thoroughly led to the introduction in England, about 1860, of a method known as the chemical precipitation of sewage. This consists in adding to the sewage certain chemical compounds which produce a voluminous flocculent precipitate which, when the sewage thus treated is allowed to remain quiescent in a large tank for some time, settles to the bottom of the tank, carrying down with it the suspended solids of the sewage, leaving a clear supernatant liquid. The chemical compound first employed for this purpose was lime, which was added to the sewage in the form of milk of lime. The action of lime depends upon its combining with the carbonic acid and soluble carbonates in the sewage to form insoluble calcium carbonate, which in settling out carries down with it the suspended solids. The quantity of lime which it is necessary to employ depends upon the character of the sewage, an acid sewage requiring more than one which is neutral or alkaline. If too little lime is added to the sewage, sedimentation takes place slowly and it is impossible to obtain a clear effluent; on the other hand, with the addition of too much lime, varying quantities of the suspended organic matter in the sewage are rendered soluble, thus causing the effluent to be more putrescent and obnoxious than that from ordinary sedimentation.

In the Landreth Direct Oxidation Process for the treatment of sewage, both electricity and lime are employed. The efficacy of the process, as will be seen later, depends upon the combination of these agents, neither electricity nor lime alone producing such good results. The electric current liberates at the electrodes oxygen and hydrogen which in the nascent state are claimed to

[3] Kennicut, L. P., Winslow, C. E. A., and Pratt, R. W.: "Sewage Disposal," 1919. John Wiley & Sons, New York.

promote the destruction of pathogenic bacteria, and a reduction of the nitrogenous organic matter to albuminoids, peptones and amino compounds, which are subsequently oxidized to nitrites, nitrates and carbon dioxide. The presence of lime furnishes not only an alkaline medium which lowers the electrical resistance of the sewage and renders the electrodes passive, thus very greatly

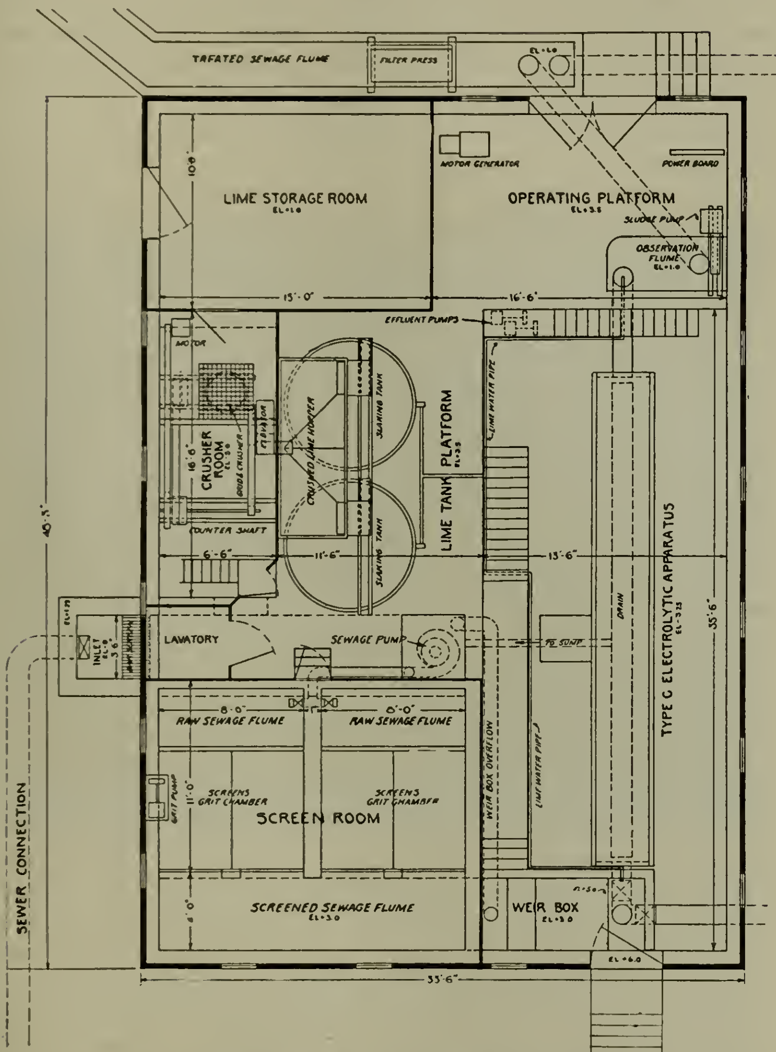
Fig. 1.

decreasing the quantity of iron which passes into solution from the anode, but it also aids in sedimentation. The process differs from others that employ electricity, in that purification is effected neither by the action of dissolved iron as a coagulant, nor primarily by the disinfecting action of nascent chlorine produced by electrolysis.

The Landreth process has been extensively studied at the 750,000 gallon unit installed at Elmhurst, Long Island, in 1915, by Messrs. Mason, Olsen and Mailloux, and by the Bureau of Sewer Plan of New York City; and later at Decatur, Illinois. Since then the process has been somewhat altered, and in the Spring of 1918 a plant with a million gallon unit embodying the

inventor's improvements was erected at Easton, Penna., by Mr. Landreth for demonstration purposes.

FIG. 2.




## II. DESCRIPTION OF PROCESS AND PLANT.

The plant at Easton occupies a corner site, at Front and Spring Garden Streets, adjoining one of the city recreation parks, and is only two squares distant from the business centre of the city.

Its location in the heart of the residential district and the entire absence of complaints and unfavorable comments indicate that the plant is not considered a nuisance, and that the nearby residents are not annoyed by odors or other objectionable features. The plant consists of a one-story frame building, 48 feet long and 33 feet wide (Fig. 1), the interior construction of which is illustrated by the plan shown in Fig. 2.

Sewage is obtained from the Front Street sewer, an 18-inch concrete dam having been placed below the lateral which delivers it to the plant. The area drained by this sewer is 104 acres and includes two hotels and one brewery. The approximate estimate of the population tributary to the sewer is 7000.

On entering the plant the sewage passes through a coarse screen 3′6″ x 4′, framed with bars 0.25″ thick and 1.5″ deep, placed 1.5″ apart from centre to centre, and is elevated by means of a 6″ submerged centrifugal pump to the raw sewage flume, from where it flows throughout the plant by gravity. The raw sewage flume distributes the sewage over a flat inclined screen, 6′6″ x 8′, having six 0.25″ perforated holes to the square inch. These perforations are made so that the smooth surface is upwards. The material caught by this screen is removed continuously by five brushes 60″ in length arranged on a traveler. The sewage passes through this screen to a grit chamber and then on to a 3-foot measuring weir, the crest of which is of steel. The gauge for measuring the flow is placed four feet back from the crest of the weir, the zero of the gauge corresponding to the elevation of the weir crest. The discharge has been calculated by the Bazin formula which gave results proportional to the depth of the discharge over the weir. After being mixed with milk of lime at the spillway of the weir, the sewage passes through the electrolytic apparatus and enters the observation flume, from which it can be either passed through a sedimentation basin or discharged directly into the river.

The solid material obtained from the bar-screen which protects the centrifugal pump consists largely of paper and labels from the bottling house of a nearby brewery and amounts on an average to about 20 pounds per million gallons. Above the grit chamber the flat screen collects from two to three pails, each of three gallons, per 24 hours. The greatest part of these screenings consists of grain and hops from the brewery and vegetables from the hotel kitchens, very little fæcal matter being found.

The electrolytic apparatus (Fig. 3 and Fig. 3a) consists of a horizontal cypress box, 27′3″ long, 3′ wide and 2′9″ deep, mounted on supports 18″ above the floor. The top of the apparatus, which is removable, is made in two sections bolted to the sides and made water-tight with a rubber gasket. Vents are provided in each section of the top for the gaseous products of electrolysis, and a series of valves in the bottom of the tank serve to remove any sediment that may be deposited.

FIG. 3.

Internally, the tank is divided into eleven spaces, each of which contains two banks of electrodes (Fig. 4.) mounted one above the other, giving a total of twenty-two banks of electrodes arranged in two horizontal rows of eleven each. These banks of electrodes, each of which consists of 48 mild steel plates, 10″ x 16″ x 3/16″, spaced 3/8″ apart, are placed across the tank, the plates being vertical and parallel to the sides. The 48 plates of each bank are electrically connected so that alternate plates have the same polarity. The spaces between the banks and the sides of the tank are blocked up, compelling the sewage to flow between the

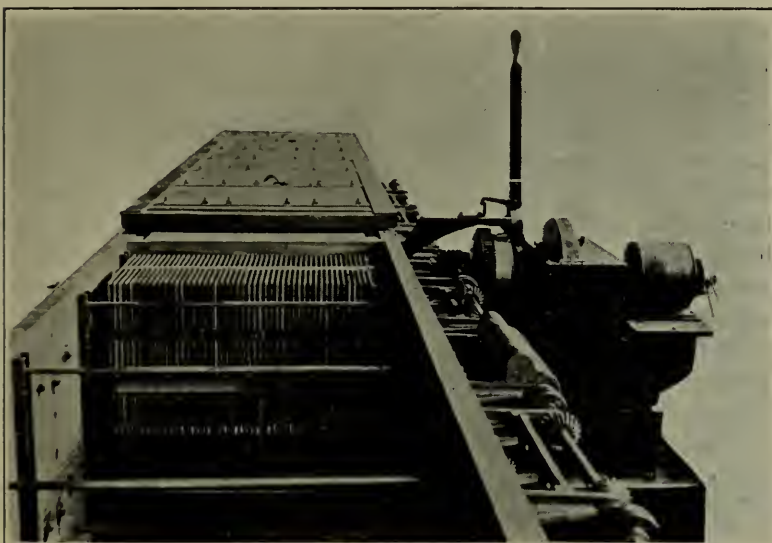
$\frac{3}{8}''$ spaces between the electrodes. There are no partitions or baffle plates, the sewage flowing straight through the tank from one end to the other. The electric current passes through the twenty-two cells in series, but as these are all in the same body of liquid there is necessarily some leakage of current from one set of electrodes to another through the liquid, and the electricity which leaks in this way performs electrolysis less than twenty-two times.

Fig. 3a.

In each of the $\frac{3}{8}''$ spaces between the electrodes, two paddles or agitators are revolved, being attached to shafts passing through holes punched in the electrodes to receive them. These paddles are placed between the electrodes when the banks are assembled, their hubs being so shaped and interlocked that they remain in position to receive the shaft and insulate it from the electrodes. An electric motor drives the paddles at a speed of 20 R.P.M., the power being transmitted through the double reduction gear box and the two banks of protected bevel gears shown in Fig. 3a and Fig. 4. The two shafts for revolving the paddles are, for each two

banks of electrodes, electrically connected by means of braces in the outside mechanism for driving them; each pair is insulated from the next by a leather coupling. The voltage between two neighboring pairs of shafts is about 6, or about equal to that of two cells. This necessarily gives rise to internal cross-currents which reduce the electrolytic action, but this reduction is probably not large. A more serious result is that those shafts which act as anodes to this leakage current will become corroded electrolytically. This could be avoided entirely by omitting the connecting braces, thereby insulating each shaft from all of the others, leaving only the leakage current which may enter the same shaft, which is presumably very small, if indeed it exists at all.

FIG. 4.



As each electrode has an unobstructed area of 120.2 square inches per side, and as the 48 plates of each bank of electrodes are electrically connected so that alternate plates have the same polarity, each bank contains 5649.4 square inches of positive and negative electrode area respectively. The total positive and negative electrode area in the electrolytic apparatus, which contains 22 banks of electrodes, is, therefore, 124,286.6 square inches, respectively. The total number of paddles is 2068.

With the arrangement just described, the sewage is brought into intimate contact with the electrodes, thus enabling the nascent oxygen and hydrogen to be used effectively. In its course through the tank the sewage flows for 14 feet 8 inches between electrodes, and for 11 feet 10 inches through the spaces at the ends, in the middle and through the spaces between the banks of electrodes, which latter spaces are 7 inches. Hence during about 55 per cent. of the time or distance of flow through the tank, the sewage is under electrolytic treatment, and during 45 per cent. it is not.

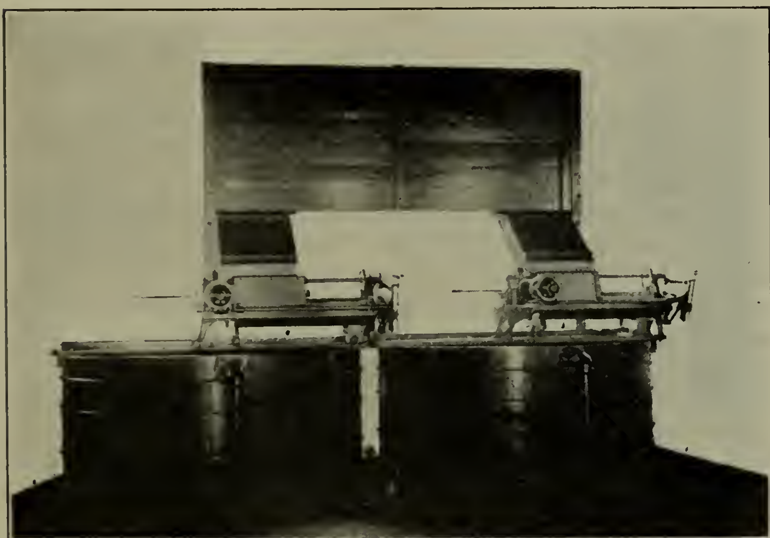
Experiments carried out by the inventor for the purpose of determining the life of the mild steel plates which constitute the electrodes, have shown that the total amount of iron removed from the electrodes by the current amounts to 1.41 pounds per 24 hours, and is not in any way influenced by the volume of sewage treated. This figure has been substantiated by tests made by the writers. As each plate weighs 8.33 pounds, and there are 48 plates in each of the 22 banks of electrodes, the total weight of the electrodes is, therefore, 8796.5 pounds. Assuming that two-thirds of the metal can be removed from the electrodes without rendering them useless, it follows that 5864.3 pounds of iron can pass into solution without destroying the electrodes. On account of frequent reversal of polarity, the loss of iron is distributed between all the electrodes. From the figures just given, it is evident that the life of the electrodes should be about 11.4 years, and that the electrolytic corrosion of the iron is a negligible factor. The electrodes of the tank at Easton were examined by the writers, after having been in use for many months, and showed no visual signs of wear, the edges being still sharp.

At this plant provisions are made for using either lump or hydrated lime. When lump lime is used the lumps are broken up on a 3-inch grid placed over the crusher, which reduces it to the size of cracked corn and discharges it into the boot of an elevator. A spout is provided so that hydrated lime may enter the elevator directly. The crushed or hydrated lime is elevated to a divided overhead hopper mounted above the two slaking tanks (Fig. 5), each of which is 7 feet in diameter and 3 feet high, only one of which is used at a time. The lime is discharged from the overhead hopper into either of these slaking tanks at their sides by adjustable feeding devices which are mounted on trusses supported by the sides of the tanks, and are actuated by the same motor that drives the agitator in the bottom of the tank.

Either city water or, as is generally the case, the effluent from the process is used for slaking the lime. The effluent is pumped into the bottom of either of the tanks by a one-inch centrifugal pump connecting with the observation flume and the milk of lime is discharged from the top of the tanks through suitable piping into the spillway of the weir or into the outlet pipe of the electrolytic apparatus.

The construction of the feeding device is very simple, consisting of a reciprocating link driven by an eccentric, which by

FIG. 5.



means of pawls and a ratchet actuates the feed worm. The quantity of lime discharged into the slaking tanks depends upon the number of revolutions of the feed worm and this may be controlled by changing the position of the eccentric or by varying the number of teeth engaged on the ratchet by changing the position of the pawl arm, permitting a total of 87 adjustments.

It has been mentioned previously that one of the functions of the lime is to render the electrodes passive, so that they will not be corroded by electrolytic action. After the electrodes have become passive, the crystalloids of calcium carbonate produced by the action of the lime on the sewage begin to accumulate on them. This increases the power required to rotate the paddles, which

is indicated by a watt-meter placed in the circuit of the motor that drives them. When this motor indicates 2000 watts, the addition of lime to the spillway of the weir is discontinued and it is then admitted to the outlet pipe of the electrolytic tank. Under these conditions the acid content of the sewage dissolves the crystalloid deposit without affecting the production of nascent hydrogen and oxygen. As soon as the watt-meter reading becomes normal (1000–1200 watts), the lime is again admitted to the spillway of the weir and its addition to the outlet pipe of the electrolytic apparatus discontinued.

The normal operation of this process requires that the effluent from the electrolytic apparatus shall contain 30 p.p.m. excess CaO. Should this excess be decreased, the resultant coagulation is poor, and when greatly increased the coagulation is not improved, but the crystalloid deposit upon the electrodes forms very rapidly, necessitating the reversal of the point of lime dosage at shorter intervals.

During the operation of the electrolytic apparatus, the occlusion of hydrogen and oxygen by the electrodes causes a considerable increase in resistance, and it is therefore necessary at four-hour intervals to change the polarity of the electrodes by a switch on the powerboard in order to counteract this phenomenon. This maintains the electrodes in a passive condition and keeps the resistance of the apparatus practically constant, while the production of nascent hydrogen and oxygen is unimpaired. An increase in resistance is also occasioned by electrolytic depositions on the electrodes taking place. This is indicated by a rise in the voltage of the electrolytic apparatus and a fall in the current strength. When, therefore, the voltage and the current strength attain certain values, the direction of the current is reversed and then these deposits re-dissolve.

The method of operation that has been adopted at Easton to take care of the wide variations in both the flow and the character of the sewage is exceedingly simple and ensures satisfactory results at all times, but it is much more expensive than would be the case were the sewage flow equalized, as more lime is required continuously to take care of the variations of the sewage.

The total consumption of energy *chargeable directly to the process* is that used for electrolysis, that for driving the paddles, that for pumping a portion of the effluent into the lime-mixing tank, and that for driving the stirrer and feeder of this tank.

All this energy, and none other, is measured in a sealed General Electric Company's kilowatt-hour meter attached directly to a three-phase, 60-cycle, 220-volt alternating current. Part of the current which passes through this meter operates a motor generator, which furnishes the direct current for electrolysis. That portion of the total power which as direct current passes through the electrolytic tank, is read separately on a voltmeter and ammeter; that portion which is used for driving the paddles located between the electrodes is measured on a separate indicating wattmeter.

The voltage of the individual cells ranges from 2.5 to 3.7 volts, averaging about 2.82 volts, while a current of 34 ampères is flowing.

### III. EXPERIMENTAL RESULTS.

In order to determine the efficacy of the Landreth Direct Oxidation Process, an investigation was carried out at the demonstration plant at Easton, on February 18th, 19th, 20th and 21st, during which time the plant was operated under the direction and constant supervision of one of the writers and his two assistants, Messrs. O. R. Quayle and J. D. Ballard. Composite samples of both the raw sewage and the effluent were prepared from half-hour samples of these liquids, and the chlorine, nitrite, nitrate, required oxygen and dissolved oxygen were determined in the former samples immediately after obtaining them. Portions of these composite samples were sent at once to Mr. James DeLong, at Lafayette College, Easton, Pa., who made determinations of albuminoid and free ammonia. The bacteria content was determined by Dr. E. Q. St. John, of Philadelphia, in samples of both the raw sewage and the effluent taken every two and one-half hours, or oftener, during the runs. The bacteria samples were kept on ice and sent to Philadelphia daily by special messenger.

One litre of each composite sample of raw sewage and of effluent was placed in bottles of that volume, with only a small air space at the top to allow for expansion, and sent to the Chemical Laboratories of Swarthmore College, where the dissolved oxygen remaining in the samples at the end of five days and the suspended matter were determined.

Owing to the fact that the composition of the raw sewage delivered to the plant was liable to vary greatly from moment to moment, it was necessary, in order that the influence of the elec-

trolytic-lime treatment might be ascertained, to determine the time required for the sewage to pass from the point where the samples of raw sewage were collected, to that point where the samples of effluent were taken. This was accomplished by adding a suitable dye to the sewage at the first point and noting the time required for the color to appear at the second point. From the spillway of the weir, and from the entrance to the grit chamber, points at which samples of raw sewage were collected, 95 seconds, and 3 minutes, respectively, were required by the sewage to pass to the observation flume where the samples of effluent were taken. Therefore, by allowing this time to elapse between taking the samples of raw sewage and effluent, there were obtained corresponding samples. It might be of interest to mention that several of the dyes employed, as well as phenolphthalein, were decolorized while passing through the electrolytic apparatus. The individual samples of both raw sewage and effluent, of which the respective composite samples were composed, were made by dipping up three portions of 250 c.c., thirty seconds elasping between each dip.

During the tests covered by analyses 1 to 9 inclusive, the hydrated lime was fed into the mixing vat at the rate of 856.4 pounds per 24 hours, or an equivalent of 672 pounds 90 per cent. CaO lump lime. The milk of lime so formed was added to the raw sewage at the spillway of the weir at the rate of 30 gallons per minute. The lime was found on analysis to contain:

| | Per cent. |
|---|---|
| $CaO$ | 71.36 |
| $Fe_2O3+Al_23$ | 2.47 |
| Cl | 0.5 |
| $CO_2$ | 0.0 |

The purification process, *operated in the manner recommended by the inventor* (*i.e.,* the use of electricity and lime), was tested over a period of 35.5 hours, this period being made up of a run of 14.5 consecutive hours on February 18th, during which three composite samples for chemical analysis and six samples for bacteriological examination were taken; and a run of 10 and another of 3 consecutive hours on February 19, covered by three composite samples for chemical analysis and nine samples for bacteriological examination; and a run of 5 and another of 3 consecutive hours on February 19th, covered by two composite samples for chemical analysis and 6 samples for bacteriological examination. During these three days the weather was cold and fine.

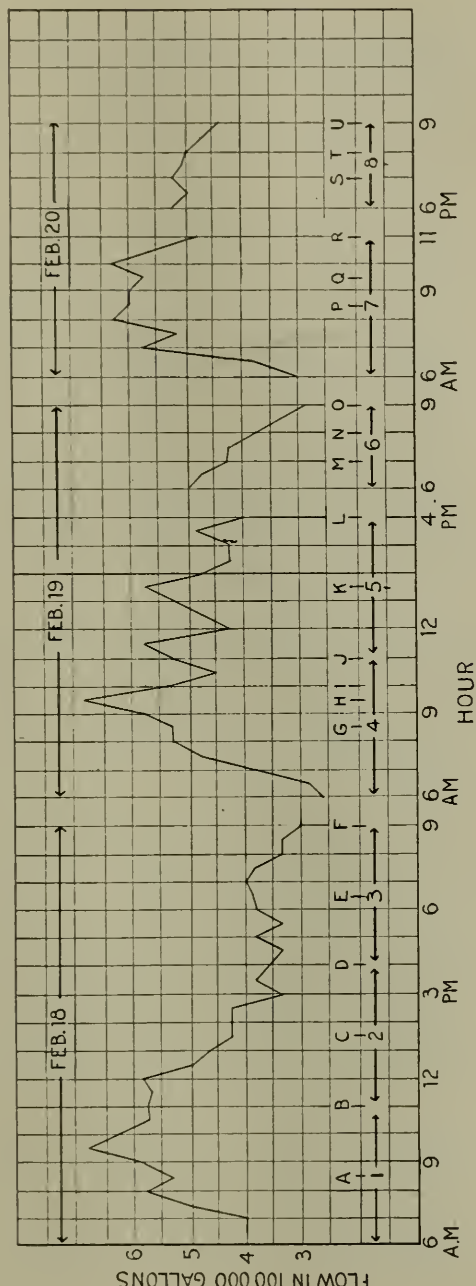

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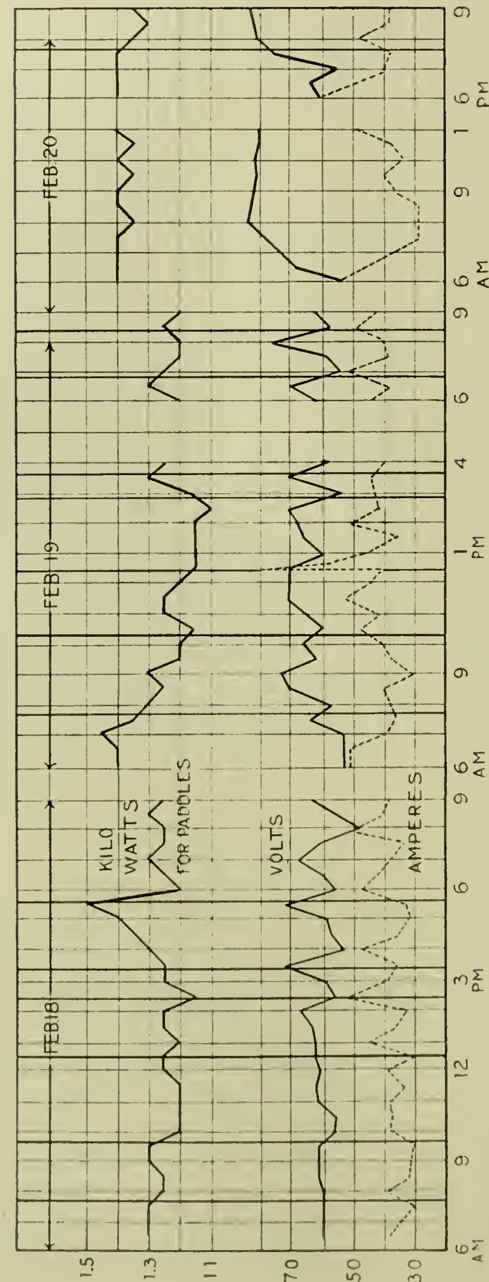
Fig. 6.

Fig. 7.


KILO WATTS FOR PADDLES
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Variations in the flow of sewage during these periods are shown by the curves in Fig. 6. In this figure are indicated by the numerals, 1 to 8, the periods covered by the composite samples taken for chemical analysis, and by the letters, *a* to *u*, the times at which samples were taken for bacteriological examination.

In Fig. 7 are shown graphically the variations in the voltmeter, ammeter and wattmeter readings. The hours at which the direction of the current through the electrolysis tank was reversed are indicated by the heavy vertical lines. It will be seen that, for the most part, the current was reversed when the voltage was high and the ampèrage low. Further, it will be observed that the form of the voltage and ampèrage curves on February 20th is quite different from those for the two preceding days, a high voltage being necessary to maintain the normal operating current. On this day a considerable quantity of grease was observed in the effluent. It is believed that the presence of the grease considerably increased the electrical resistance of the sewage.

In Table I are given the analytical data and the average of the bacteriological data obtained for the periods indicated, for both the raw sewage and for the effluent.

As it had been suggested that the efficiency of the process was due primarily to the action of the lime which was thoroughly mixed with the sewage in the electrolytic apparatus, electricity playing but a minor part, the examination at Easton included an investigation of the efficacy of the apparatus in the purification of sewage, (1) when the raw sewage, after having been mixed with the usual quantity of lime suspension, was passed through the tank and subjected to thorough mixing by the paddles, without electricity; and (2) when the raw sewage to which no lime had been added was subjected to the action of the electric current in the tank. As the inventor was of the opinion that the electrode would be damaged by allowing the lime-containing sewage to flow through it in the absence of the electric current, or by operating it with electricity in the absence of lime, for periods longer than one hour, the tests just mentioned each extended over a period of sixty minutes. During these two periods composite samples were prepared by taking portions of both the raw sewage and the effluent at intervals of five minutes, while for bacteriological examination samples were taken every ten minutes during the

TABLE I.

*Landreth Direct Oxidation Process.*

*Regular Practice: Electrolytic-Lime Treatment.*

*R = raw sewage. E = apparatus effluent.*

| No. of composite sample | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Average | Change P. P. M. | Change Per cent. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Chlorine, P. P. M. | R | 55.5 | 65.6 | 64.6 | 60.5 | 70.3 | 64.5 | 56.5 | 58.1 | 61.9 | | |
| | | E | 63.0 | 77.6 | 65.2 | 44.6 | 60.3 | 61.8 | 64.8 | 67.9 | 63.1 | + 1.2 | + 1.9 |
| Nitrogen as— | Nitrite, P. P. M. | R | 0.009 | 0.025 | 0.030 | 0.035 | 0.025 | 0.019 | 0.033 | 0.028 | 0.024 | | |
| | | E | 0.028 | 0.043 | 0.036 | 0.050 | 0.030 | 0.028 | 0.023 | 0.040 | 0.038 | + 0.014 | +58.3 |
| | Nitrate, P. P. M. | R | 0.62 | 0.52 | 0.50 | 0.46 | 0.75 | 0.67 | 0.50 | 0.41 | 0.55 | | |
| | | E | 0.77 | 0.64 | 0.60 | 0.50 | 0.63 | 0.85 | 0.83 | 0.63 | 0.68 | + 0.13 | +23.6 |
| | Free Ammonia, P. P. M. | R | 17.2 | ..... | ..... | 17.0 | ..... | 17.8 | 19.8 | ..... | 18.0 | | |
| | | E | 15.6 | ..... | ..... | 13.9 | ..... | 14.4 | 14.8 | ..... | 14.7 | − 3.3 | −18.3 |
| | Albuminoid $NH_3$ P. P. M. | R | 27.9 | ..... | ..... | 32.2 | ..... | 29.3 | 29.6 | ..... | 29.8 | | |
| | | E | 26.3 | ..... | ..... | 28.1 | ..... | 25.2 | 25.3 | ..... | 26.2 | − 3.6 | −12.1 |
| | Required oxygen P. P. M. | R | 51.4 | 71.2 | 65.8 | 61.9 | 74.9 | 64.5 | 59.0 | 59.5 | 63.5 | | |
| | | E | 43.0 | 54.1 | 58.6 | 43.6 | 55.4 | 51.2 | 52.0 | 46.2 | 50.5 | −13.0 | −20.5 |
| Dissolved Oxygen | Determined Immediately, P. P. M. | R | 3.88 | 3.90 | (6.55) | 4.26 | 5.09 | 5.22 | 3.98 | 4.14 | 4.35 | | |
| | | E | 7.39 | 5.92 | 5.76 | 5.76 | 6.40 | 6.20 | 5.14 | 6.22 | 6.13 | + 1.78 | +40.9 |
| | Determined after 5 days (10–15), P. P. M. | R | 0.21 | 0.19 | 0.26 | 0.15 | 0.22 | 0.28 | 0.09 | 0.05 | 0.18 | Absorption of oxygen on standing: in P. P. M. R = 4.17, E = 0.77; in % R = 95.9, E = 12.6 | |
| | | E | 6.70 | 5.64 | 5.57 | 4.11 | 6.14 | 5.75 | 4.06 | 4.98 | 5.36 | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Suspended solids, P. P. M. . | E | 256 | 268 | 169 | 293 | 271 | 193 | 251 | 182 | 235 | | |
| Temperature, | R | 7.4 | 7.5 | 7.5 | 7.7 | 7.9 | 7.9 | 8.9 | 9.1 | 8.0 | | |
| °C. . . . . . . . . | E | 8.1 | 8.3 | 8.4 | 8.6 | 8.8 | 8.8 | 9.7 | 9.9 | 8.8 | | |
| Bacteria: Total count per | R | 215000 | 155000 | 250000 | 312000 | 475000 | 425000 | 527000 | 603000 | 370000 | | |
| c.c., at 37° . . . | E | 28000 | 6000 | 27400 | 25000 | 37000 | 20300 | 32300 | 37300 | 26800 | −343200 | −92.7 |
| Total count per | R | 500000 | 455000 | 625000 | 530000 | 550000 | 757000 | 1017000 | 1533000 | 746000 | | |
| c.c., at 20° . . . | E | 82000 | 40000 | 42000 | 91000 | 62000 | 47000 | 47000 | 51000 | 58000 | −688000 | −92.2 |
| B. coli per c.c. . | R | 100000 | 100000 | 55000 | 100000 | 55000 | 70000 | 100000 | 40000 | 78000 | | |
| | E | <10 | <10 | <10 | 250 | <10 | <10 | 670 | 0 | 120 | −77880 | −99.85 |
| Period in hours | | 4.5 | 5 | 5 | 5 | 5 | 3 | 5 | 3 | | | |
| No. half-hour samples in composite . . . | | 9 | 10 | 10 | 10 | 10 | 6 | 10 | 6 | | | |
| Average flow of sewage in 1000 gals. per 24 hrs. | | 543 | 446 | 358 | 468 | 481 | 388 | 532 | 496 | 464 | 213 kw. h. for 686,000 gals. | |
| Power consumed, kw. hours . . . . . . . | | 29 | 26 | 29 | 28 | 33 | 21 | 33 | 24 | | | |
| Kw. h. per hour | | 6.4 | 5.2 | 5.8 | 5.6 | 6.6 | 7.0 | 6.6 | 8.0 | 6.4 | | |
| Kw. h. per 1000 gals. sewage. | | 0.29 | 0.28 | 0.39 | 0.29 | 0.33 | 0.43 | 0.29 | 0.38 | 0.335 | | |

hour. These tests were made on February 21st, on which day there was a light fall of snow which melted rapidly. The variations in the sewage flow during the two tests are shown graphically in Fig. 8, and the electrical data are shown in Fig. 9. The results of the chemical analyses and the bacteriological examination which cover the two tests are given in Table II.

Fig. 8.

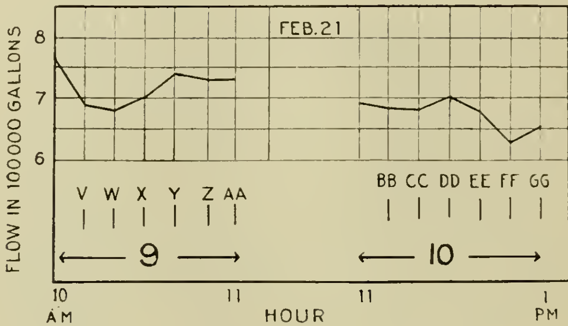
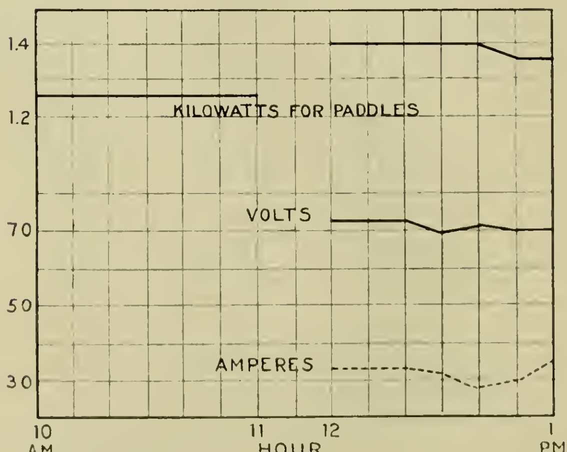



Fig. 9.




## IV. DISCUSSION OF RESULTS.

Various standards for the purity of sewage effluents have been formulated from time to time. Kinnicutt, Winslow and Pratt state in their book just published that " in the United States the usual requirement is that the effluent must be non-putrescible, or must contain only that amount of organic matter which, when

TABLE II.

| | | | Lime treatment. Only in the Landreth Apparatus. Composite sample No. 9 | | | Electrical treatment. Only in the Landreth Apparatus. Composite Sample No. 10 | | |
|---|---|---|---|---|---|---|---|---|
| | | | P. P. M. | Change P. P. M. | Change per cent. | P. P. M. | Change P. P. M. | Change per cent. |
| | Chlorine | R | 67.7 | | | 70.8 | | |
| | | E | 80.0 | +12.3 | +18.2 | 72.4 | +1.6 | + 2.2 |
| Nitrogen as | Nitrite | R | 0.050 | | | 0.050 | | |
| | | E | 0.045 | − 0.005 | −10.0 | 0.040 | −0.01 | −20.0 |
| | Nitrate | R | 0.62 | | | 0.75 | | |
| | | E | 0.625 | + 0.005 | + 0.8 | 0.60 | −0.15 | −20.0 |
| | Free $NH_3$ | R | 15.6 | | | 13.5 | | |
| | | E | 15.8 | + 0.2 | + 1.3 | 14.4 | +0.9 | + 6.6 |
| | Albuminoid $NH_3$ | R | 23.8 | | | 22.2 | | |
| | | E | 23.4 | − 0.4 | − 1.7 | 21.7 | −0.5 | − 2.3 |
| | Required oxygen | R | 84.6 | | | 64.5 | | |
| | | E | 76.9 | − 7.7 | − 8.9 | 58.0 | −6.5 | −10.0 |
| Dissolved Oxygen | Determined immediately | R | 4.88 | | | 4.01 | | |
| | | E | 3.95 | − 0.93 | −19.1 | 5.62 | +1.61 | +40.1 |
| | Determined at end of 5 days | R | 0.03 | Absorption of oxygen on standing: in P. P. M. R=4.85, E=3.82; in % R=99.4, E=96.7 | | 0.08 | Absorption of oxygen on standing: in P. P. M. R=3.93, E=5.17; in % R=98.0, E=92.0 | |
| | | E | 0.03 | | | 0.45 | | |
| Bacteria * | Total count per c.c., at 37° C. | R | 1,180,000 | | | 437,000 | | |
| | | E | 453,000 | ........ | −82.4 | 272,000 | ........ | −37.8 |
| | Total count per c.c., at 20° C. | R | 1,192,000 | | | 908,000 | | |
| | | E | 118,000 | ........ | −90.1 | 273,000 | ........ | −70.0 |
| | B. coli per c.c. | R | 100,000 | | | 55,000 | | |
| | | E | 3,700 | ........ | −92.3 | 10,000 | ........ | −81.8 |

R = Raw sewage. E = Effluent.
* Bacteria values are the average of six samples taken every 10 minutes during an hour.

the effluent is emptied into a stream, can be oxidized by the oxygen contained in the water at the time of the minimum flow; and that it must be sufficiently freed from suspended solids to avoid the accumulation of sludge banks or the creation of surface conditions offensive to sight and smell. In certain cases, as when the effluent is emptied into a stream in the near neighborhood of a point at which water is taken for domestic use, or is emptied into salt water in the neighborhood of shellfish layings, the effluent must also be freed from the great majority of the sewage bacteria."

"The International Boundary Commission, as a result of its study of pollution in the Great Lakes, suggested that the raw water to be treated by a purification plant should contain not over 500 *B. coli* per 100 c.c. as an annual average, and should not show *B. coli* in more than half of a series of 0.1 c.c. samples if satisfactory results are to be secured. According to this standard it would naturally be required that sewage treatment should be carried far enough so that after dilution has taken place the effluent discharged shall not produce, at any neighboring water works intake, a raw water of greater bacterial impurity than that specified above. The requirement of the Commission is perhaps an unduly strict one since many filtration plants (such as that of Cincinnati) are treating waters much more polluted than this with success."

"Authorities in America generally consider that more valuable information can be obtained from the study of the nitrogen data than from any of the other factors, while in England and Germany greater importance is placed on the oxygen consumed. If total carbon could be determined easily, this determination would probably be most valuable. Oxygen consumed, however, does not bear a constant relation to total carbon and is open to the same objections as albuminoid nitrogen."

"The latest and most authoritative standard of this kind is the one formulated by the Royal Commission on Sewage Disposal in its Eighth Report (R.S.C., 1912). It provides as a general standard that a sewage effluent must not contain as discharged more than 30 parts per million of suspended matter and must not take up more than 30 parts per million of dissolved oxygen in 5 days at 18.3° C. If the volume of diluting water available is 150–300 times the volume of the effluent the dissolved oxygen

test may be omitted and 60 parts of suspended solids would be permissible; if the volume of diluting water is 300–500 times the volume of the effluent the limit of suspended solids may be raised to 150 parts; while if the diluting volume is 500 times that of the effluent all standards might be dispensed with provided necessary screens and detritus tanks were provided."

In Table III are compared the changes brought about in raw sewage by:

1. Electrolytic-lime treatment with the Landreth apparatus;
2. Lime alone with the Landreth apparatus;
3. Electricity alone with the Landreth apparatus.

TABLE III.

*Change Produced in Sewage by the Landreth Apparatus Operated With:*

| | Lime and Electricity | | Lime alone | | Electricity alone | |
|---|---|---|---|---|---|---|
| | P. P. M. | Per cent. | P. P. M. | Per cent. | P. P. M | Per cent. |
| Chlorine | + 1.2 | + 1.9 | +12.3 | +18.2 | +1.6 | + 2.2 |
| Nitrite | + 0.014 | +58.3 | − 0.005 | −10.0 | −0.01 | −20.0 |
| Nitrate | + 0.13 | +23.6 | + 0.005 | + 0.8 | −0.15 | −20.0 |
| Free ammonia | − 3.3 | −18.3 | + 0.2 | + 1.3 | +0.9 | + 6.6 |
| Album. $NH_3$ | − 3.6 | −12.1 | − 0.4 | − 1.7 | −0.5 | − 2.3 |
| Required oxygen | −13.0 | −20.5 | − 7.7 | − 8.9 | −6.5 | −10.0 |
| Dissolved $O_2$ | + 1.78 | +40.9 | − 0.93 | −19.1 | +1.61 | +40.1 |
| Dissolved ... R = | 4.17 | 95.9 | 4.85 | 99.4 | 3.93 | 98.0 |
| $O_2$ absorbed in 5 days ...... E = | 0.77 | 12.6 | 3.82 | 96.7 | 5.17 | 92.0 |
| Bacteria Reduction: Total count at 37° C., per c. c. | −343,200 | −92.7 | − 373,000 | −82.4 | −165,000 | −37.8 |
| Bacteria Reduction: Total count at 20° C., per c. c. | −688,000 | −92.2 | −1,074,000 | −90.1 | −635,000 | −70.0 |
| Bacteria Reduction: B. coli at 37° C., per c. c. | − 77,880 | −99.85 | − 96,300 | −92.3 | −45,000 | −81.8 |

From a comparison of the results recorded in Table III, it will be observed that with electrolytic-lime treatment the quantities of nitrite and nitrate in the sewage are increased, while with lime alone and with electricity alone a material decrease or but a slight increase is effected. With the electrolytic-lime treatment there is a marked decrease in free ammonia and albuminoid ammonia, whereas with the lime or with the electrical treatment

there is a small decrease in albuminoid ammonia, and an increase in free ammonia. The required oxygen is decreased by all three treatments, but that effected by the electrolytic-lime treatment is approximately double that brought about by either of the other methods. Due to the production of oxygen by the electric current, an increase in dissolved oxygen of about 40 per cent. is effected by the electrolytic-lime treatment and by the purely electrical treatment; while with lime alone a decrease of 19 per cent. in dissolved oxygen occurs.

The amount of the dissolved oxygen absorbed by the effluent in five days at a temperature of 10° C. to 15° C., affords very important information regarding the efficiency of the three methods of treatment. Indeed this test is regarded by many authorities as one of the most important standards for determining the purity of an effluent. The results recorded in Table III show that while practically all of the dissolved oxygen in the raw sewage is absorbed during the five-day period, that in the effluent produced by the electrolytic-lime treatment is reduced only 0.77 part per million, or 12.6 per cent., a figure which lies far below the limit allowed by the Royal Sewage Commission. On the other hand, nearly all of the dissolved oxygen in the effluents produced by the lime treatment and by the electrical treatment is absorbed in the five-day period, showing that by these methods the unstable organic matter in the sewage was but partially oxidized.

It will be observed that electrolytic-lime treatment brings about a reduction of over 92 per cent. in the total bacteria count, while the lime treatment effects a reduction of 82 per cent. at 37° C. and 90 per cent. at 20° C., and the electrical treatment produces a reduction of only 38 per cent. at the higher temperature and 70 per cent. at the lower temperature. The reduction in *B. coli* per c.c. amounts to 99.85 per cent. with the electrolytic-lime treatment, and to 92.3 per cent. and 81.8 per cent., respectively, with the lime treatment and with the electrical treatment.

It may be of interest to mention that the effluents produced by the different treatments were examined after having been kept in stoppered bottles for five weeks. Those obtained in runs 1 to 8 (electrolytic-lime treatment) had little or no odor; that obtained in run 9 (lime treatment only) had a very disagreeable odor, while that obtained in run 10 (electrical treatment only) smelled strongly of hydrogen sulphide, and had turned black

owing to the conversion of the iron dissolved from the electrodes into iron sulphide.

It is evident from the data recorded in Table III that not only is an highly satisfactory effluent produced by the Direct Oxidation Process, but that the combination of lime and electricity, when employed in the apparatus described, is much more effective in purifying sewage than either lime alone or electricity alone when employed with the same apparatus.

In judging the efficacy of the Direct Oxidation Process, it must be remembered that the data given in the preceding tables refer to the effluent as it comes from the electrolytic tank, and that by the conjunctive use of a sedimentation basin the suspended solids, consisting largely of lime, could be considerably reduced. This reduction would also be attended by a further decrease in albuminoid ammonia, required oxygen and the bacteria.

In order that the results obtained with the Direct Oxidation Process of sewage treatment may be compared with those obtained with other methods, analytical and bacteriological data relating to a number of methods are given in Tables IV and V.

### V. COSTS AND COMPARISONS.

After a careful study of 16 different plants for sewage treatment in this country, varying in cost from $40,000 to $9,000,000, we still find it extremely difficult to make a comparison in cost either of construction or of operation of the electrolytic process of sewage treatment with other methods, since the conditions affecting the installation of a sewage treatment system vary greatly and frequently involve factors which in the aggregate are more costly than the construction of the plant.

Take, for instance, the selection of a site for a treatment plant. It must be sufficiently remote to avoid offense; its elevation should be low enough to receive the sewage by gravity or at least to minimize the cost of pumping; and it ought also to be reasonably close to a stream furnishing a proper outlet for the effluent. To meet these general conditions, heavy costs may be incurred in the purchase of land suitable for the purpose and frequently tracts thus acquired must be largely in excess of the actual needs of the plant so as to avoid the depreciation of adjacent land values. The cost also may be increased by the construction of long and expensive trunk line sewers; the construction of collecting basins and pumping stations for the purpose of lifting

Table IV.

*Effect of Various Processes for the Treatment of Sewage.*

| Process | Location | Suspended solids | Albuminoid $NH_3$ | Free $NH_3$ | Nitrates | Nitrites | Required oxygen | Authority |
|---|---|---|---|---|---|---|---|---|
| | | in parts per million | | | | | | |
| Chemical pptn. $CaO+FeSO_3$: | London, 1894 | | | | | | | Dibdin, 1903. |
| Sewage | | 441 | 4.9 | 34.8 | ... | ... | 53.1 | |
| Effluent | | 87 | 3.9 | 28.9 | ... | ... | 44.5 | |
| Coke strainer: | Lawrence, Mass., average 4 years (1894–1898) | | | | | | | Winslow and Phelps, 1906. |
| Sewage | | ... | 6.4 | 30.8 | ... | ... | 38.8 | |
| Effluent | | ... | 3.3 | 31.8 | ... | ... | 22.2 | |
| Septic tank: | Lawrence, Mass., average 5 years (1898–1903) | | | | | | | Winslow and Phelps, 1906. |
| Sewage | | 232 | 7 | 38.1 | ... | ... | 49.5 | |
| Effluent | | 107 | 3.3 | 37.7 | ... | ... | 27.3 | |
| Sedimentation: | Birmingham, England | | | | | | | |
| Sewage | | 686 | 14.2 | 39.3 | 7 | ... | 66 | Watson, 1903. |
| Effluent | | 346 | 10.9 | 37.7 | 7.3 | ... | ..... | |
| Broad irrigation: | South Norwood, England | | | | | | | Royal Sewage Commission, 1904. |
| Sewage | | 219 | 6.7 | 35.4 | ... | ... | 77.1 | |
| Effluent | | ... | 1 | 8.7 | 3.9 | ... | 14.4 | |
| Contact beds: | Mansfield, Ohio, 1907. | | | | | | | |
| Sewage | | 74 | 7.8 | .... | 0.4 | 0.2 | 37 | Kimberly. |
| Effluent | | 40 | 3.6 | .... | 2.6 | 0.04 | 9.2 | |
| Intermittent filtration: | Worcester, Mass., 1904 | | | | | | | Kinnicutt, Winslow and Pratt. |
| Sewage | | ... | 8.1 | 18 | 0.6 | 0.1 | 138.7 | |
| Effluent | | ... | 0.9 | 10.9 | 2 | 0.3 | 18.1 | |
| Trickling filters: | Worcester, Mass., 1913 | | | | | | | Kinnicutt, Winslow and Pratt. |
| Sewage | | 144 | 6.7 | 24.3 | 0.7 | ... | 119 | |
| Effluent | | 43 | 2.3 | 17.8 | 6 | ... | 29 | |

the sewage across divides from one drainage area into another, so that treatment can be obtained at a central plant; and the property damages which in some cities result from the widening of streets and the changes of grades made necessary to accommodate concentrated drainage.

TABLE V.

*Bacteria Reduction by Various Methods for Treating Sewage.*

Intermittent Filtration at Brockton, Mass.

Kinnicutt, Winslow and Pratt.

| | Total count per c.c. at 20 | *B. coli per* c.c. |
|---|---|---|
| Raw sewage | 3,150,000 | 150,000 |
| Effluent A | 1,900 | 400 |
| Effluent B | 6,300 | 15 |
| Effluent D | 125 | 0 |
| Effluent E | 1,400 | 5 |
| Effluent F | 2,000 | 1 |

Results of Experiments at Lawrence, Mass.

Metcalf and Eddy.

| | | Per cent. bacteria removed |
|---|---|---|
| Regular sewage, as received from force main at station | 2,095,600 | |
| Settled sewage | 1,386,300 | 33.80 |
| Effluent, strainer E (12″ depth buckwheat coal, rate 800,000 gals. per acre per day) | 874,200 | 58.50 |
| Fresh sewage (from toilet room at station) | 3,241,600 | |
| Effluent, Imhoff tank | 1,700,300 | 46.60 |
| Effluent, sand filters | 2,565 | 99.88 |
| Effluent, contact filters | 1,105,600 | 47.20 |
| Effluent, trickling filters | 254,500 | 81.70 |

While it is true that in the electrolytic process described in this paper, a number of units are eliminated which are required in ordinary treatment systems, yet in a small electrolytic plant this saving is more than offset by the cost of the protective building which is necessary. In addition there is the constant employment of skilled labor which such a plant requires. Where it is possible to combine a water pumping station, an electric lighting plant, and a Landreth Direct Oxidation sewage treatment plant under one roof, the proportional cost of the protective structure, as well as operation, is reduced, making it a probable advantage to employ this method. When this cannot be done, the Landreth Direct Oxidation process is not in our judgment economical if the population tributary to the plant is very small.

Our experience at the Landreth Direct Oxidation plant in

Easton fully justifies the statement that a plant of this type can be installed and operated in any densely populated section without detection by the public.

The importance of this advantage is evident when it is considered that an inexpensive property of a few thousand square feet conveniently situated near outlets of main sewers is all that is required for this electrolytic process compared with the large areas at a distant point demanded by ordinary methods of sewage disposal.

Table VI.

*Comparison of Cost of Operation Between 2,000,000 Gallon Plant and 10,000,000 Gallon Plant.*

Capacity ....................2,000,000 gallons per day.
Population ................ 20,000.

The operation cost is based upon the following daily items:

| | |
|---|---|
| 1600 lbs. 90 per cent. lime per day at $6 per ton ........ | $5.33 |
| Current, 282 k.w. hrs. per day at 2 cents .............. | 5.64 |
| Heat and light per day ............................ | 2.00 |
| Renewals ........................................ | 2.00 |
| Maintenance and repairs ............................ | 1.00 |
| *Labor:* | |
| 3 men—8 hr. shifts, at $5, $4, $4. | |
| 1 laborer at $3 .................................. | 16.00 |
| Total ............................................ | $31.97 |

This is 58 cents per capita per year for operation, of which about 51 per cent. is for labor alone.

Capacity ..................10,000,000 gallons per day.
Population ................ 100,000.

The operation cost is based upon the following daily items:

| | |
|---|---|
| 8000 lbs. 90 per cent. lime per day at $6 per ton ........ | $26.75 |
| Current, 1410 k.w. hrs. per day at 2 cents .............. | 28.00 |
| Heat and light per day (estimated) .................. | 2.00 |
| Renewals ........................................ | 10.00 |
| Maintenance and repairs ............................ | 6.00 |
| *Labor:* | |
| 1 superintendent .................................. | 5.00 |
| 3 operators at $4 .................................. | 12.00 |
| 1 laborer ........................................ | 3.00 |
| | $92.75 |

This is 34 cents per capita per year for operation, of which about 22 per cent. is for labor.

TABLE VII.

*Cost of Operation, Allowing Interest at 4 per cent. and 2½ per cent. Depreciation.*

| Location | Cost of plant | Population | Int. and dep. per cap. | Cost of oper. per cap. | Total cost per cap. | Authority | Remarks |
|---|---|---|---|---|---|---|---|
| Chicago | $9,258,600.00 | 1,600,000 | $.38 | $.27 | $.65 | Hering & Fuller | Includes intercepting sewer and pumping station. |
| N. Dist. Boston, Mass. | 7,126,000.00 | 601,810 | .77 | .29 | 1.06 | H. P. Eddy | Water dilution. |
| S. Dist. Boston, Mass. | 8,944,000.00 | 438,580 | 1.33 | .25 | 1.58 | H. P. Eddy | Water dilution. |
| Worcester, Mass. | 1,966,000.00 | 162,697 | .79 | .37 | 1.16 | H. P. Eddy | Chemical precipitation and sand filters. |
| Fitchburg, Mass. | 815,000.00 | 39,655 | 1.34 | .26 | 1.60 | H. P. Eddy | Imhoff and trickling filters. |
| Gloversville, N. Y. | 378,000.00 | 21,178 | 1.16 | .27 | 1.43 | H. P. Eddy | Sedimentation and trickling filters. |
| Clinton, Mass. | 149,000.00 | 13,192 | .73 | .57 | 1.30 | H. P. Eddy | Sand filters, and pumping station. |
| Lebanon, Pa. | 80,000.00 | 15,000* | .34 | .65 | .99 | P. A. Volcknor | Imhoff and trickling filters. |
| York, Pa. | 194,500.00 | 30,000 | .42 | .11 | .53 | J. K. Geisey | Imhoff and pumping station. |
| West Chester, Pa. | 162,000.00 | 12,000 | .88 | .30 | 1.18 | N. R. Rambo | Pumping plant and septic tank. |
| Indiana, Pa. | 40,000.00 | 8,000 | .32 | .10 | .42 | Metcalf & Eddy | Septic tanks and trickling filter. |
| Typical plant† | 431,710.00 | 55,000 | .51 | .31 | .82 | H. P. Eddy | Imhoff and trickling filter. |
| Typical plant† | 313,880.00 | 55,000 | .37 | .73 | 1.10 | H. P. Eddy | Activated sludge. |
| Electrolytic plant† | 219,050.00 | 55,000 | .26 | .38 | .64 | Landreth | Electrolytic. |

* Refers to population served by plant.
† No main sewer lines included in estimates of costs.

TABLE VIII.

*Cost of Construction.*

| Location | Cost | Population for which plant was designed | Cost per cap. at time of use | Authority | Year of establishment | Remarks |
|---|---|---|---|---|---|---|
| Chicago, Ill. | $9,258,600.00 | 1,600,000* | $5.78 | Hering & Fuller | 1907 | Includes trunk line sewers and trickling beds. |
| N. Dist., Boston, Mass. | 7,126,000.00 | 571,000 | 12.48 | H. P. Eddy | 1916 | Dilution in harbor. |
| S. Dist., Boston, Mass. | 8,944,000.00 | 986,000 | 9.07 | H. P. Eddy | 1916 | Dilution in harbor. |
| Worcester, Mass. | 1,966,000.00 | .......... | 9.31 | H. P. Eddy | 1916 | Chemical precipitation and sand filters. |
| Fitchburg, Mass. | 815,000.00 | .......... | 12.88 | H. P. Eddy | 1916 | Imhoff tanks, etc. |
| Gloversville, N. Y. | 378,000.00 | .......... | 15.26 | H. P. Eddy | 1916 | Sedimentation tanks and filters. |
| Clinton, Mass. | 149,000.00 | 18,700 | 7.96 | H. P. Eddy | 1916 | Sand filters and pumping station. |
| Lebanon, Pa. | 80,000.00 | 17,500 | 4.57 | P. A. Volckner | 1916 | Does not include outfall sewer. |
| York, Pa. | 194,463.58 | 30,000 | 6.48 | J. K. Geisey | 1916 | Includes outfall sewer and sand filters. |
| West Chester, Pa. | 162,000.00 | 12,000 | 13.50 | N. R. Rambo | 1915 | Includes outfall sewer and pumping station. |
| Indiana, Pa. | 40,000.00 | 8,000 | 5.00 | Metcalf & Eddy | 1914 | Plant only. |
| Typical plant | 431,710.00 | 55,000 | 7.85 | H. P. Eddy | 1916 | Imhoff tank and trickling filter. No trunk line sewer. |
| Typical plant | 313,880.00 | 55,000 | 5.71 | H. P. Eddy | 1916 | Activated sludges. No trunk line sewer. |
| Electrolytic plant | 219,050.00 | 55,000 | 3.99 | Landreth | 1916 | Does not include outfall sewers. |

* Estimated.

In the operation of this electrolytic process it is imperative to have skilled labor in constant attendance, although the duties imposed upon it are light. However, in this process the number of units can be largely increased without any appreciable increase in the amount of labor necessary to operate the enlarged plant. This is illustrated by the data contained in Table VI showing comparisons between the operating costs of 2,000,000 gallon and 10,000,000 gallon plants.

In Table VII is given the cost of construction of various sewage disposal plants in the United States. It has not been possible in this table to indicate in every case the actual cost of the disposal plant alone, eliminating property values, trunk lines, costs, etc., and on that account the per capita costs show such great variations. It is evident, however, that the per capita cost of the construction of a Direct Oxidation plant compares favorably with that of any other process.

The data in Table VIII indicate the actual cost of operation per capita of a number of sewage disposal plants in the United States with the additional costs for interest and depreciation. An examination of this table indicates that the economy resulting from the use of the Landreth Direct Oxidation process is effected largely through a saving in the cost of construction.

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**Fire Engines and the Essentials of Fire Fighting.** CHARLES H. FOX. (*The American Society of Mechanical Engineers,* Spring Meeting, June, 1919.)—Steam power was not successfully applied to fire engines until the beginning of the year 1853. Up to that time the so-called " hand engines " were used exclusively and it should also be understood that at that time the present-day system of water-works, was still in its infancy and, therefore, the chief dependence for a supply of water for fire-extinguishing purposes was upon methods of storage in vogue before water mains came into general use.

The conventional hand fire engine of that day comprised a rectangular wooden box suitably mounted on four low wheels. Pumps, of the piston type, were housed within and firmly fixed to the floor of the box; working levers were provided and motion was imparted to the pistons by a host of firemen lined up on opposite sides of the apparatus. At this early period fire hose was not plentiful, the best was crudely made up of leather, and the pumps were, therefore, placed close to the scene of the fire. Water, largely conveyed by a

hand-to-hand passing of fire-pails, was poured into the engine trough, where it was picked up by the pumps and forced through the leading hose and onward to be thrown on the fire. Somewhat later it became customary to equip these hand engines with a non-collapsible suction hose, so that water could be drawn directly from cisterns or wells, but the wooden tub or reservoir always remained a characteristic feature of these old-time machines.

Early in January, 1853, Mr. A. B. Latta successfully tested his new steam-driven fire engine. Mr. Latta was a citizen of Cincinnati and although his pioneer effort resulted in the production of an extremely heavy machine, the engine was purchased by the city and known as the Joe Ross. The first steamer marked the beginning of a new epoch in fire fighting.

Latta's second steam fire engine was built and installed in the year 1853. The purchase of this machine was made possible by popular subscription and the engine was named and long known in Cincinnati as the Citizens' Gift.

When fire must be fought, fire streams can be effective only when the water is expelled from the nozzle at an appropriate speed. In other words, unless enough of the initial pressure available for starting the flow through the hose survives at a point immediately back of the nozzle orifice, the resulting jet will not measure up to its mission. The characteristics of a fire stream—good, bad, or indifferent—are directly dependent upon the velocity of the jet and obviously the velocity is proportionate to the surviving pressure just mentioned. For the best results the flow may be too slow, while, on the other hand, disappointment will follow when the velocity of discharge goes beyond what might be termed the maximum economical limits of nozzle pressure.

The function of a fire engine is either to draw water from any basin or other conveniently located source or, when fire hydrants are available, to make up the pressure, which is seldom high enough in ordinary water mains to serve for effective fire service. In fighting fire, it is not uncommon to elevate the nozzle far above the source of the water supply. This procedure, of course, involves loss of forcing pressure, which is in proportion to the static head of the column. The greatest power-absorbing medium between the source of supply and the point of discharge is the fire hose. In may also be said that here is involved the point which is least understood in the subject of hydraulics as applied to fire-fighting practice.

# SOME REMARKS CONCERNING THE HEAT TREATMENT OF STEEL AND THEIR APPLICATION TO THE TREATMENT OF STEELS USED FOR AIRPLANE MOTORS.* [1]

BY

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In heat treating rolled or forged steel we seek generally:

1. To increase its softness, that it may be more readily machined;

2. To make it strong, that it may resist successfully the stresses to which it will be subjected in use:

3. To make it hard, that it may resist wear or acquire cutting properties.

The corresponding heat treatments may be therefore described respectively as:

(*a*) Softening Treatment,
(*b*) Strengthening Treatment,
(*c*) Hardening Treatment.

*The Softening Treatment,* which usually consists in cooling the metal slowly from a temperature exceeding its critical range, generally imparts to it its maximum ductility but materially reduces its strength (and elastic limit).

It is also highly beneficial in removing the strains resulting from the working of the metal. These strains are the more serious and detrimental the lower the temperature at which the metal was worked. If it has been cold worked, the necessity of removing them becomes imperative, as a strained metal is a dangerous one, inclined to be brittle and having reduced resistance to shock and to fatigue stresses.

*The Strengthening Treatment* implying, as it generally does, a rapid cooling from a temperature but slightly above the critical range of the metal, is not as effective as the softening treatment in removing working strains. It follows from these considera-

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* Communicated by the Author.

[1] A few copies of these remarks were printed for private circulation in February, 1918, as Bulletin M 3, "Notes on the Metallurgy of Aviation," by the Technical Section, U. S. Air Service, American Expeditionary Forces.

tions that it is often advisable to subject to a softening treatment certain steel objects already soft enough to be readily machined or which are to be subjected to a strengthening treatment, for the purpose of removing thoroughly the objectionable strains created by the working operation.

The softening treatment should be logically applied after rolling or forging but before machining.

The strengthening treatment consists usually in cooling rapidly through the critical range and may be followed, as later explained, by a second heating below that range.

Roughly speaking, the strength imparted will be the greater, the quicker the cooling through the range. Increased strength moreover generally implies increased elastic limit, a property which is in reality of greater moment than mere tenacity, for, obviously, it is not intended that steel parts should ever be strained above their elastic limit, that is, until permanent distortion actually occurs.

The strengthening treatment, on the other hand, generally decreases the ductility of the metal and may result in actual brittleness. Broadly stated, the greater the increase of strength, the greater generally the decrease of ductility, that is, the greater the danger of producing a brittle metal; hence the necessity, in most cases, of being satisfied with such strengthening treatment as will yield, not maximum strength, but such strength as can be combined with the amount of ductility necessary for safety, that is, to guard us against sudden rupture under shock. If, for instance, the cooling through the range has been so rapid as to yield very great strength but very little ductility, a second treatment will be required in order to increase the ductility, while necessarily decreasing the strength.

The rapid cooling through the range which the strengthening treatment generally implies is, moreover, beneficial in destroying, in part at least, the structural orientation generally imparted to steel by work. An objectionable effect of this orientation is to cause the metal to acquire physical properties when tested in the direction of the work markedly different from those it possesses when tested at right angle to that direction. In the former case, for instance, the ductility as measured by the elongation is, as a rule, considerably greater. This implies a lack of physical or structural homogeneity obviously undesirable.

Again, the strengthening treatment generally increases in a

marked degree the hardness of the metal, and hence, imparts to the treated parts greater resistance to wear. Great softness then, cannot be generally combined with great strength, nor great strength with much ductility. Softening and strengthening treatments must necessarily be distinct and generally of opposite nature, the former implying slow cooling through the critical range, the latter a more rapid cooling. Moreover, the maximum strength the metal is capable of acquiring can seldom be utilized because of the lack of ductility, if not actual brittleness, which accompanies it.

The strengthening operation must be so conducted as to yield such combination of strength and elastic limit with ductility, as will meet the requirements of the case.

*The Hardening Treatment,* like the strengthening treatment, consists in cooling rapidly through the critical range.

In hardening steel, however, the primary requirement is to produce very great hardness, while overlooking the decrease of ductility implied. Indeed, as a rule, we use all possible means to hasten the cooling because of the greater hardness resulting.

Even when implements are to be hardened and thereby deprived of much of their ductility, a softening treatment preceding the hardening treatment may often be applied with beneficial results because by more thoroughly removing the forging or rolling strains it will diminish the danger of cracks occurring during the quenching in the subsequent hardening treatment.

The rational methods of conducting these three treatments may now be briefly described.

### A. SOFTENING TREATMENT.

*Purpose.*—To soften the metal in order to facilitate machining; also to remove the strains produced by forging or rolling.

*When to Apply.*—After forging or rolling, but before machining.

*Description.*—(*a*) Heating the steel to 900° C. (1652° F.), maintaining that temperature for 30 minutes or more, cooling slowly, for instance with the furnace in which the steel was heated. (*b*) Heating to some 600–675° C. (1112–1247° F.) for several hours, cooling very slowly. (*c*) Heating to some 800–850° C. (1472–1562° F.), quenching in oil, then treatment *b*.

Treatments (*b*) and (*c*) are applicable to steels containing 0.8 per cent. carbon or more, and to some alloy steels which are not readily softened by treatment (*a*).

### B. STRENGTHENING TREATMENT.

*Purpose.*—To increase strength and elastic limit at the sacrifice of some ductility; also to increase hardness, and, in some cases, resistance to shock and to fatigue stresses and to decrease structural orientation.

*When Applied.*—Generally after machining in the case of machined parts; after forging, rolling or stamping, if the objects are not to be machined.

*Description.*—(*a*) Heating to 50° C. (90° F.) above the critical range of the steel,[2] cooling freely in air. Steels containing less than 0.25 per cent. carbon may be quenched in oil, those with less than 0.15 per cent. carbon in oil or in water. (*b*) Heating to 50° C. (90° F.) above the critical range of the steel; quenching in water or oil (the former for low carbon steel), re-heating to 50° C. (90° F.) or more below the critical range, cooling in air, oil or water.

The rate of cooling from a temperature inferior to the critical range does not generally affect the properties of steel very materially; at least its tensile properties. The higher the temperature of the second heating the less tenacious and more ductible the metal.

Some nickel-chromium steels, however, show very low shock strength under impact testing after heating to some 600° C. (1112° F.) followed by *slow cooling* as compared to their shock strength after quenching from that temperature.

While treatment (*a*) often yields satisfactory results, treatment (*b*) affords a means of securing greater strength, as well as many different combinations of strength and ductility to meet different requirements. The steels so treated, especially certain alloy steels, are generally also more resistant to shock and to fatigue stresses. There is little if any advantage, however, in applying treatment (*b*) in preference to treatment (*a*) to carbon steels containing less than 0.25 per cent. carbon.

### C. HARDENING TREATMENT.

*Purpose.*—To produce very great hardness while sacrificing ductility to the point of brittleness.

*When Applied.*—To finished parts, as a last treatment, or to be followed by grinding only.

*Description.*—Heating to 50° C. (90° F.) above the critical

[2] Heating steel slightly above its critical range refines the structure, heating it to a much higher temperature coarsens it.

range of the steel, cooling rapidly in water or oil, generally re-heating to 200–400° C. (392–732° F.), an operation known as tempering, which is applied in order to remove or decrease the severe strains created by the sudden cooling while losing but little hardness and to decrease brittleness. The higher the tempering temperature, the greater the softening effect of the operation.

The three basic heat treatments described above are applicable to alloy steels as well as to carbon steels bearing in mind the marked influence of some elements on the position of the critical range. Some special steels, for instance, should be heated, for the purpose of strengthening or of hardening, to temperatures considerably lower than those suitable for carbon steel, because of the lower position of their critical range. The character of the operation, however, remains the same.

*Classification of Steel According to Heat Treatment Required.*—According to the heat treatments required, steels may be classified as follows:

(1) Steels soft enough to be readily machined and strong enough for the stresses to which they will be subjected in service. *Heat Treatment Required.*[3]—None.

(2) Steels soft enough to be readily machined, but lacking in strength or in hardness. *Treatment to be Applied.*[3]—Strengthening treatment (*a*) or (*b*) generally after machining, and, for hardness, hardening treatment.

(3) Steels not soft enough to be readily machined but strong enough for the uses to which they are intended. *Treatment to be Applied.*—Softening treatment (*a*), (*b*) or (*c*) followed, generally after machining, by strengthening treatment (*a*) or (*b*), because the softening treatment will generally deprive the steel of much of its strength, which must then be restored.

(4) Steels neither soft enough to be readily machined nor strong enough to resist stresses in service. *Treatment Required.*—Softening treatment (*a*), (*b*) or (*c*) followed, generally after machining, by strengthening treatment (*a*) or (*b*).

It will be noted that steels of classes 3 and 4 call for similar treatments.

(5) Steel parts which should be very hard must be treated by

[3] It is important to remember that the softening treatment is also beneficial in removing the strains caused by rolling or forging and that for these reasons it may be applied with good results even to steels soft enough to be readily machined.

the hardening treatment unless they already possess great hardness, such as manganese steel and air or self-hardening steels, which will be considered later.

As already stated, it is beneficial to subject to a preliminary softening and strains—removing treatment steel parts to be hardened.

When for economical or other reasons it is advisable to subject forged or rolled carbon steel to but a single heat treatment, cooling in air from a temperature of some 800–900° C. (1472–1652° F.), according to its carbon contents, is generally to be recommended, because such treatment (1) leaves the steel in a condition generally soft enough to permit its ready machining (unless it be very high in carbon), (2) removes, in part at least, the working strains, (3) obliterates, or at least, mitigates, the structural orientation and (4) yields a fair proportion of the strength combined with a large proportion of the ductility which the metal is capable of acquiring.

### HEAT TREATMENT OF CASE-HARDENED PARTS.

Case-hardened parts generally require:

1. A strengthening and toughening treatment for the core consisting in quenching from 900 to 950° C. (1652–1742° F.) followed by

2. A refining and hardening treatment of the case consisting in quenching from a temperature some 50° C. (90° F.) above the critical range, which for carbon steel would be in the vicinity of 800° C. (1472° F.). Special steels with lower critical range should, of course, be quenched from correspondingly lower temperatures. For nickel and nickel chromium steels, single quenching from some 800° C. (1472° F.) is often sufficient. After quenching for hardening the case the parts may be tempered at some 200–300° C. (392–572° F.) in order to diminish the strains and the brittleness of the case.

There are a few instances of special steels demanding treatments different from those applicable to all other steels. These exceptions should be briefly mentioned:

*Manganese Steel.*—A steel very hard and wear-resisting, even after slow cooling. To make it ductile, however, it should be heated to 1000° C. (1832° F.) or thereabout and quenched in water.

*Self- or Air-hardening Steels.*—These steels become intensely

hard on simple air cooling from a temperature of some 800 to 850° C. (1472–1562° F.). They do not therefore need any hardening treatment and they may be softened by softening treatment (*b*).

*High-speed Steels.*—These steels, in order to acquire their remarkable physical properties, must be heated to a very high temperature approaching the melting point of the metal and quickly cooled in air or in oil. They may then be tempered at a temperature not exceeding generally 600° C. (1112° F.). To soften these steels, in order to machine them, they may be heated to 750°–850° C. (1382°–1562° F.) for several hours and very slowly cooled.

*High Nickel Steels.*—That is, those containing 25 or more per cent. nickel, are softened by quenching.

### APPLICATION OF THE FOREGOING CONSIDERATIONS TO THE HEAT TREATMENT OF THE STEELS USED FOR THE CONSTRUCTION OF AIRPLANE MOTORS.

Adopting the classification of the steels used in the construction of aviation motors, proposed in previous reports (Bulletins M1 and M4) the heat treatments they should receive may be inferred from the rules just outlined:

#### STEEL TYPE I.

Medium-hard carbon steel containing from 0.30 to 0.40 per cent. carbon. In its forged, rolled or stamped condition, this steel is soft enough to be machined. It may be nevertheless subjected to a softening treatment with beneficial results for the purpose of removing the working strains as previously explained.

With that end in view, it should be heated to 900° C. (1652° F.), kept at that temperature for 30 minutes or more, and cooled slowly. This treatment should be applied logically before machining.

After machining, and in order to increase their strength and elastic limit, as well as their resistance to shock, to wear, and to fatigue stresses, the parts should be subjected to strengthening treatments (*a*) or (*b*), bearing in mind that treatment (*b*) will yield better results than treatment (*a*) and will make it possible to obtain various combinations of strength and ductility to meet various requirements.

For treatment (*a*) heat to 850° C. (1562° F.) and cool freely

in air. For treatment (*b*) heat to 850° C. (1562° F.), quench in water or oil, reheat to 450–650° C. (842–1202° F.), according to requirements, and cool slowly or in water or oil.

### STEEL TYPE II.

Low carbon steel suitable for case hardening, containing from 0.05 to 0.15 per cent. carbon. This steel in its forged, or rolled condition can be very readily machined, but it nevertheless may be subjected to a softening treatment, in order, as previously explained, to remove working strains. With that end in view, the steel should be heated to 950° C. (1742° F.) for 30 minutes, or more, and cooled slowly. This should logically be done before machining.

The case-hardened parts should then be reheated to 900° C. (1652° F.) and quenched in water or oil, in order to strengthen and toughen the core. They should then be heated to 800° C. (1472° F.) and again quenched in water or oil, in order to refine and harden the case.

They may, as a last treatment, be heated in oil to 200–300° C. (352–572° F.), in order to decrease the strains and brittleness of the case.

### STEEL TYPE III.

Low carbon nickel-chromium steel, suitable for case-hardening, containing: Carbon not over 0.15 per cent.; nickel not less than 2 per cent.; chromium not less than 0.50 per cent.; and total nickel and chromium between 2.50 and 4 per cent.

While in its forged or rolled condition this steel can be easily machined, the softening treatment may be applied to remove working strains. This should be done before machining, by heating to 900° C. (1652° F.) for 30 minutes or longer, and cooling slowly.

The case-hardened parts should be:

1. Either heated to 800° C. (1472° F.) and quenched in oil or water to refine and harden the case, or

2. Heated to 900° C. (1652° F.) and quenched in order to refine and strengthen the core, followed by heating to 775° C. (1427° F.) and quenching to refine and harden the case.

After the last quenching the parts may be tempered by heating in oil at 200° to 300° C. (392–572° F.) to diminish the strains and the brittleness of the case.

STEEL TYPE IV.

Medium-hard nickel-chromium steel containing: 0.30 to 0.40 per cent. carbon; 2.50 to 3.50 per cent. nickel; 0.5 to 1 per cent. chromium; 3 to 4 per cent. total nickel and carbon.

This steel can be machined in its forged or rolled condition, but a softening treatment will increase the ease of machining and will be beneficial in decreasing the strains caused by work.

For this treatment, which should be logically applied before machining, the steel should be heated to 850–900° C. (1562 to 1652° F.) for 30 minutes or more, and slowly cooled.

The machined parts should then be subjected to a strengthening treatment consisting in heating to 800° C. (1472° F.) followed by air cooling or preferably to the double treatment consisting in heating to 800° C. (1472° F.) and quenching in water or oil, followed by reheating to 400 to 650° C. (752 to 1202° F.) according to requirements, and quenching in oil or water.

STEEL TYPE V.

Air-hardening nickel-chromium steel, containing: 0.30 to 0.50 per cent. carbon; 3.00 to 4.50 per cent. nickel; 0.50 to 2.00 per cent. chromium; and total nickel, chromium and carbon, not less than 5 per cent.

In its forged or rolled condition, this steel is difficult to machine. It should be subjected to softening treatment (*b*).

The machined parts should then be either cooled freely in air from a temperature of 850° C. (1562° F.) or quenched in oil from 800° C. (1472° F.) and reheated to 300–600° C. (572–1112– F.) according to requirements. Air cooling suffices, however, to impart great hardness and great strength to this steel.

STEEL TYPE VI.

High speed steel, suitable for exhaust valves. To soften this steel in order to permit a small amount of machining, it may be heated to 750–850° C. (1382–1562° F.) for several hours and cooled very slowly.

The valves should then be subjected to the heat treatment generally applied to high speed steel, namely:

Heating to a temperature of some 1200° C. (2192° F.) and cooling in air or in oil. This may be followed by reheating to 500–600° C. (932–1112° F.).

**Method of Turning on Steam in Large Lines.** (*Power,* vol. l, No. 3, p. 124, July 15, 1919.)—Accidents and consequent losses, both direct, and indirect, due to the failure of steam piping and fittings while being cut into service when steam is being turned in, have apparently all been due to expansion strains rather than pressure strains. The expansion strains which caused the damage were usually different from those which were present after the line had been heated to full temperature.

A further analysis discloses the fact that the particular form of expansion causing the trouble has been in most cases due to the presence of air in the steam line at the time steam was being turned on. Air, having approximately twice the density of steam, remains at the bottom of the pipe and prevents the steam from coming in contact with (and thereby expanding) parts of the piping. On a straight run of horizontal piping the result has a tendency to "rainbow" the piping. This has been proved by actual test. The further result of this action is to put a heavy compression strain on the upper half of all joints and fittings and a corresponding tensile strain on the lower half. This trouble is experienced to a greater extent with large than with small piping. This may be due either to the pipe being so small that the air and steam do not remain stratified, or possibly to the great flexibility of the small piping.

The method of turning on steam, which will prevent trouble of this kind, is as follows:

All drains and air vents on the line are opened. Steam is turned into the line very rapidly, the valve being opened one-fourth to one-half its full opening. This applies not only to low pressure, but to high pressure as well. This procedure results in driving the air out of the line very rapidly and allows the pipe to heat uniformly. To engineers who have been accustomed to "warming up" slowly, or "soaking" the line, this method will no doubt seem dangerous, but the results obtained from close observation and actual test indicate that it is the best that can be followed.

The same phenomena take place in starting up a steam turbine. In the Parsons type of machine where the blade and clearances are small, the "warming up" method of starting is likely to cause blade failures, because when a machine is standing still, the spindle and cylinder "rainbow" in the same direction, but as soon as the spindle revolves one-half a revolution, the top of the spindle (then at the bottom), unless the clearances are large, rubs the bottom of the cylinder. The new method is to open the throttle quickly until the spindle starts to revolve, after which the throttle is almost closed again, allowing the turbine to revolve slowly until the heat is evenly distributed.

## GIMBAL STABILIZATION.*

BY

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### GENERAL.

The following is an analysis of the effectiveness of gimbals of various designs for maintaining a horizontal platform on shipboard, and of gyroscopic stabilizing of such devices.

Gimbals can never maintain a platform absolutely horizontal, for there always will be a certain deviation.

The motion of the ship in the waves can affect the gimbals in three ways, namely by reason of (1) horizontal motions impressed upon the support, (2) vertical motions impressed upon the support, and (3) tipping of the support.

If the friction of the gimbals about the pivots is small, as must always be the case in a good design, the third effect is entirely negligible. The second effect comes in only when the supported platform deviates from the horizontal. If the angle of deviation is small, as it must be in a case of practical value, the second effect is also negligible. There remains to be considered only the first point, the effect of moving the support horizontally. It is sufficient to consider a single plane only, as motions at right angles produce independent effects. The to and fro motion of the support, due to rolling or pitching of the ship in a sea, is not strictly harmonic. It is usually a rough beat motion which can be considered the sum of two sinusoidal motions of somewhat different frequencies. Each of these may be considered separately if desired. To a first approximation, however, it is sufficient to consider a simple harmonic horizontal motion of the support. Obviously the motion of the gimbals does not react appreciably to affect the motion of the ship, hence we may consider the motion of the support to be an undisturbed sinusoidal oscillation.

### PENDULUM.

The above problem is hence the problem of considering the motion of a physical pendulum of which the support is given a sinusoidal horizontal motion.

In Fig. 1, we have such a pendulum located by the coördinates

* Communicated by the Author.

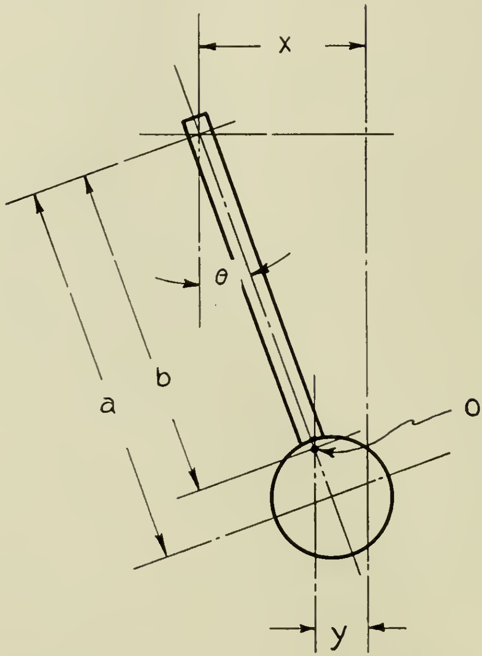
$x$ and $\theta$, where $x$ is caused to vary in accordance with the expression

$$x = A \sin \omega t$$

The pendulum has constants

$m$ = total mass
$b$ = length from centre of mass to support
$a$ = radius of gyration

Fig. 1.




It will also be convenient to use the coördinate $y$, which for the small values of $\theta$ to be considered throughout is given by

$$y = x - b\theta$$

ANALOGOUS ELECTRICAL CIRCUIT.

The formulas for forced harmonic motions of electrical circuits are in much more convenient form than the formulas for mechanical systems. It will accordingly be convenient to solve first the electrical circuit which is analogous to the mechanical system of our problem, and then to interpret the results on the problem itself.

We will consider first the simple pendulum in which

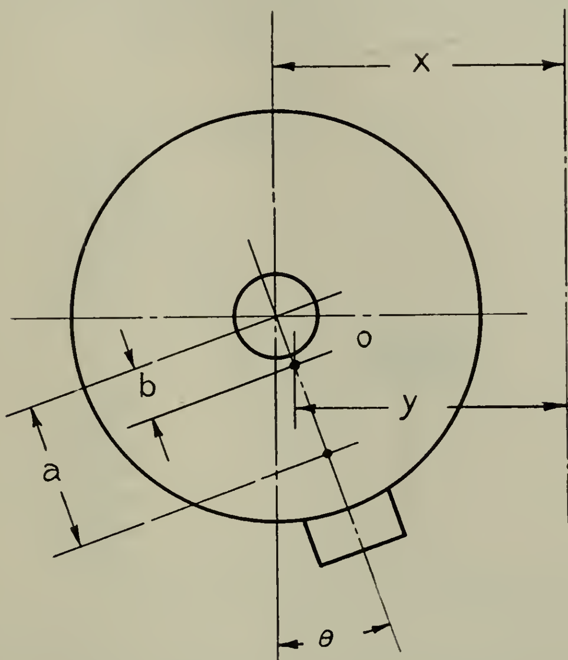
$$a = b$$

Such a pendulum when the support is moved in accordance with

$$x = A \sin \omega t$$

is analogous to the series electrical circuit of Fig. 3, containing resistance $R$, inductance $L$ and capacity $C$, when independently

FIG 2.




of the circuit a charge is supplied to the condenser in accordance with

$$q = Q \sin \omega t$$

This will be true when we have in a pair of leads connected across the condenser, the current

$$i = \frac{dq}{dt} = Q\omega \cos \omega t$$

Using the vector notation this would be written

$$I = j\, Q\omega$$

If $I_1$ is the vector current in the inductance, we may write the relation between $I_1$ and $I$ by considering that $I$ divides into parts proportional to the admittances of the two branches. That is

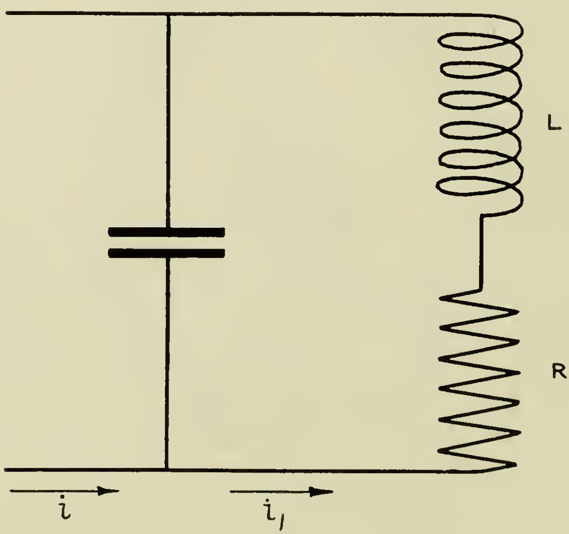
$$I_1 = I \frac{\dfrac{1}{jC\omega + \dfrac{1}{R + jL\omega}}}{R + jL\omega} = I \frac{1}{1 - LC\omega^2 + jRC\omega} = \frac{jQ\omega}{1 - LC\omega^2 + jRC\omega}$$

TRANSFER TO MECHANICAL SYSTEM.

Considerable care must be used, in interpreting this result on the mechanical system, to obtain exact analogues.

We have already set the maximum quantity $Q$ analogous to

FIG. 3.




the maximum displacement $A$. Hence the current in the leads is analogous to $\frac{dx}{dt}$ or $\dot{x}$. If a displacement $A$ is produced, and the centre of mass is simultaneously prevented from leaving the centre line, there will be, for a small angle $\theta$, a back force produced equal to $\frac{mg}{b} A$, as can be seen from Fig. 4. Analogously in the electrical circuit if a charge $Q$ is introduced through the mains, and the branch circuit is open so that this affects the condenser only, there will be a back electromotive force $\frac{Q}{C}$. We thus have $C$ analogous to $\frac{b}{mg}$.

The kinetic energy of the mechanical system in the case of a pendulum with concentrated bob is

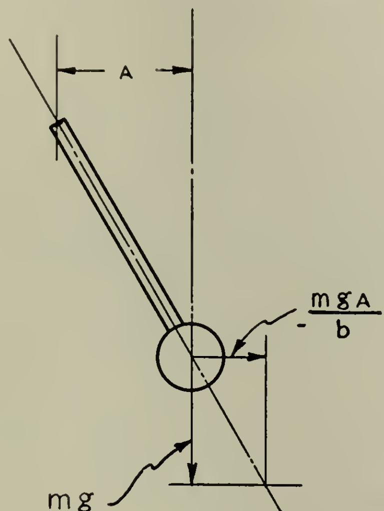
$$\frac{m\,(\dot{x}-b\dot{\theta})^2}{2}$$

and the energy stored in the magnetic field of the electrical system is

$$\frac{Li_1^2}{2}$$

Hence $L$ and $m$ are analogous; and $i_1$ corresponds to $(\dot{x} - b\dot{\theta})$ or $\dot{y}$, that is to the net horizontal speed of the centre of the bob.

FIG. 4.




The frictional constant $F$, which is the force which occurs when the bob moves at unit net constant speed, corresponds to the resistance constant $R$ which is the force arising when unit steady current flows in the branch circuit.

We may make the analogy more apparent by writing the differential equations for the two systems.

For the mechanical system, equating the forces on the bob, we have

$$m\,\ddot{y} + F\,\dot{y} = m\,g\,\theta$$

which may be arranged

$$m\,\ddot{y} + F\,\dot{y} + \frac{mg}{b}\,y = \frac{mg}{b}\,A\,\sin\omega t$$

For the electrical system, summing the voltages about the circuit

$$L\,\dot{i}_1 + R\,i_1 + \frac{1}{C}\int (i_1 - i)\,dt = 0$$

which becomes upon differentiating and substituting

$$L\,\ddot{i}_1 + R\,\dot{i}_1 + \frac{1}{C}\,i_1 = \frac{1}{C}\,Q\omega \cos \omega t$$

Place side of this the derivative of the equation for the mechanical system

$$m\,\dddot{y} + F\ddot{y} + \frac{mg}{b}\,\dot{y} = \frac{mg}{b}\,A\omega \cos \omega t$$

and we may read off immediately the analogies

$$\begin{array}{c|c} \dot{y} & i_1 \\ m & L \\ F & R \\ \dfrac{b}{mg} & C \\ A & Q \end{array}$$

Inserting these quantities in the expression above for the electrical circuit, we obtain for the mechanical system

$$\dot{y} = \frac{jA\omega}{1 - \dfrac{b\omega^2}{g} + j\,\dfrac{Fb\omega}{mg}}$$

or

$$y = \frac{A}{1 - \dfrac{b\omega^2}{g} + j\,\dfrac{Fb\omega}{mg}}$$

and since $y = x - b\theta$, and $x = A \sin \omega t$,

$$\theta = \frac{1}{b}\left(A - \frac{A}{\left(1 - \dfrac{b\omega^2}{g}\right) + j\,\dfrac{Fb\omega}{mg}}\right)$$

We are interested in the maximum value to which $\theta$ attains, and hence in the maximum value of the above vector expression, which becomes when simplified

$$\theta_{max} = \frac{A}{b}\,\frac{\sqrt{\left[\left(1 - \dfrac{b\omega^2}{g}\right)^2 - \left(1 - \dfrac{b\omega^2}{g}\right) + \left(\dfrac{Fb\omega}{mg}\right)^2\right]^2 + \left(\dfrac{Fb\omega}{mg}\right)^2}}{\left(1 - \dfrac{b\omega^2}{g}\right)^2 + \left(\dfrac{Fb\omega}{mg}\right)^2}$$

This formula checks dimensionally, thus affording an indication that the substitutions have been made correctly.

When the frictional force is zero it reduces to

$$\theta\, max = \frac{A}{b - \frac{g}{\omega^2}}$$

These formulas hold only for small values of $\theta$, and the absolute value of the result should be considered irrespective of sign.

When there is resonance, that is when the period of oscillation is the same as the natural period of the pendulum, which will occur when

$$\omega = \sqrt{\frac{g}{b}}$$

we have

$$1 - \frac{b\omega^2}{g} = O_1$$

and the formula shows that a large angle may result from even a small amplitude of oscillation of the support. On the other hand, when $b$ is very long, the angle of deviation is nearly zero.

In the above the frictional force is assumed proportional to $\dot{y}$, that is to the net velocity of the bob through the medium; and the friction of the pivot is considered negligible, as must be the case if tipping of the support is not to affect the pendulum. In many practical cases it is nearer the truth to consider the frictional force to be proportional simply to $b\dot{\theta}$, that is to consider that the medium moves with the support.

If this assumption is made, the differential equation for the mechanical system becomes

$$m\dddot{y} + F\ddot{y} + \frac{mg}{b}\dot{y} = \frac{mg}{b} A\omega \cos \omega t - F A\omega^2 \sin \omega t$$

In Fig. 3, if we alter the current leads to be connected across the coil alone, instead of the coil and resistance, the equation for the circuit becomes

$$L\ddot{i}_1 + R\dot{i}_1 + \frac{1}{C} i_1 = \frac{1}{C} Q\omega \cos \omega t - RQ\omega^2 \sin \omega t$$

The same analogy thus holds as before, and if this new circuit be solved, and the substitutions made, we obtain for the maximum deviation for the assumption that the medium moves with the pivot:

$$\theta max = \frac{A}{\sqrt{\left(b - \frac{g}{\omega^2}\right)^2 + \left(\frac{Fb}{m\omega}\right)^2}}$$

which reduces, upon setting $F = o$, to the same simple formula for the frictionless case.

PHYSICAL PENDULUM.

We will now consider the case where all of the mass cannot be considered as concentrated at a point, as is the case for the systems shown in Figs. 1 and 2.

The peculiarity of this case is that there may be kinetic energy stored in the system even when the centre of mass is not moving. If $x$ and $\theta$ are both increasing in such a manner that

$$\dot{y} = \dot{x} - b\dot{\theta}$$

is zero, there still is a kinetic energy of rotation about the centre of mass. If "$a$" is the radius of gyration about the pivot, the radius of gyration about the centre mass at a distance "$b$" from the pivot will be

$$\sqrt{a^2 - b^2}$$

and the above kinetic energy will hence be equal to

$$m \frac{(a^2 - b^2)\ \dot{\theta}^2}{2}$$

Consider now the circuit of Fig. 5, in which there is added the inductance "$l$" in series with the condenser. The circuit may store energy in a magnetic field even when there is no current in the branch circuit, that is when

$$i_1 = o\ .$$

An analogy with the mechanical system may be set up for this circuit exactly as before, and by the same reasoning as above used we have

| Electrical | Mechanical |
|---|---|
| $Q$ | $A$ |
| $i$ | $\dot{x}$ |
| $i_1$ | $\dot{x} - b\dot{\theta}$ |
| $i_2$ | $b\dot{\theta}$ |
| $C$ | $b/mg$ |

Now when $i_1 = o$, the energy in the magnetic field is

$$l\,\frac{i_2^2}{2}$$

and we see that if this is to correspond to the kinetic energy above when $i_2$ is set equal to $b\dot{\theta}$ we must have

| Electrical | Mechanical |
|---|---|
| $l$ | $m\,\dfrac{a^2 - b^2}{b^2}$ |

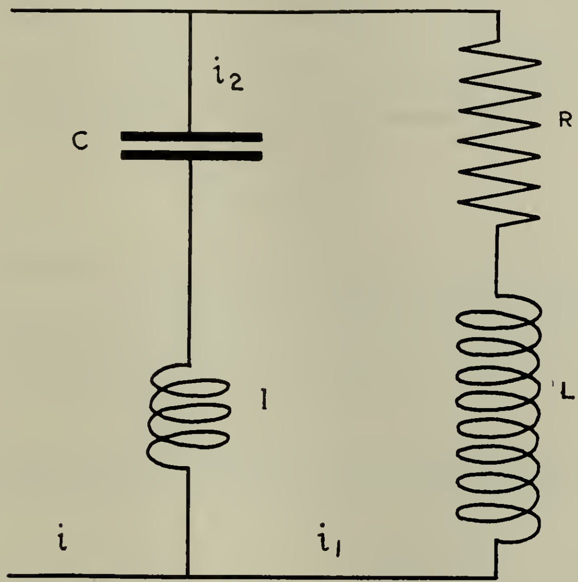
If now $b\dot{\theta}$ is taken as zero so that we have simply translation, the

kinetic energy is $\frac{m\dot{x}^2}{2}$. Also, if $i_2$ is zero so that $i = i_1$, the magnetic energy is $\frac{L\dot{i}^2}{2}$, and since $\dot{i}$ and $\dot{x}$ are analogous, we have

| Electrical | Mechanical |
|---|---|
| $L$ | $m$ |

as before.

FIG. 5.




We may check the consistency of our analogy as follows: In the electrical system assume $i = o$, and hence $i_1 = i_2$. The magnetic energy is

$$\frac{(L + l)\, i_2^2}{2}$$

Similarly in the mechanical system, assume the pivot at rest, and the pendulum simply rotating. The kinetic energy is then

$$m\,\frac{a^2\dot{\theta}^2}{2}$$

| | | |
|---|---|---|
| Hence we must have the analogy | $L + l$ | $\frac{ma^2}{b^2}$ |
| But we already have | $l$ | $m\,\frac{a^2 - b^2}{b^2}$ |
| so that we must have | $L$ | $m\,\frac{a^2}{b^2} - m\,\frac{a^2 - b^2}{b^2}$ |
| but this reduces to simply | $L$ | $m$ |

as before, giving us a check on the analogy as far as this part of the circuit is concerned.

Now in the electrical system we have

$$I_1 = I \frac{\dfrac{1}{\dfrac{1}{jlw + \dfrac{1}{jC\omega}} + \dfrac{1}{R + jL\omega}}}{R + jL\omega}$$

$$= jQ\omega \frac{1 - lC\omega^2}{1 - (l + L)\,C\omega^2 + jRC\omega}$$

Hence by analogy in the mechanical system we have

$$Y = \frac{jA\omega\left(1 - \dfrac{a^2 - b^2}{b - g}\right)\omega^2}{1 - \dfrac{a^2\omega^2}{bg} + j\dfrac{Fb\omega}{ng}}$$

and from this by the same process of reduction as used before, we may obtain for the case of the medium at rest:

$$\theta max = \frac{A}{B}\frac{\sqrt{\left[\left(1 - \dfrac{a^2\omega^2}{bg}\right)^2 - \left(1 - \dfrac{a^2\,\omega^2}{bg}\right)\left(1 - \dfrac{a^2 - b^2}{bg}\omega^2\right) + \left(\dfrac{Fb\omega}{mg}\right)^2\right]^2 + \left(\dfrac{Fb\omega}{ng}\right)^2\left(1 - \dfrac{a^2 - b^2}{bg}\omega^2\right)^2}}{1 - \left(\dfrac{a^2\omega^2}{bg}\right)^2 + \left(\dfrac{Fb\omega}{mg}\right)^2}$$

It will be noted that this formula reduces to the one derived for a simple pendulum when $a = b$, and also that it is dimensionally correct.

When $F = o$ it reduces to

$$\theta max = \frac{A}{\dfrac{a^2}{b} - \dfrac{g}{\omega^2}}$$

This formula is particularly interesting in showing that when $\frac{a^2}{b}$ is large, that is with a pendulum of large radius of gyration, mounted only slightly away from its centre of mass, the angle of deflection will be very small. Also resonance may be obtained exactly as before, the frequency of oscillation in this case being

$$\frac{1}{2\pi}\sqrt{\frac{gb}{a^2}}$$

### GYROSCOPIC STABILIZATION.

The effect of a very long pendulum may be obtained in an instrument of small dimensions by the use of the gyroscope.

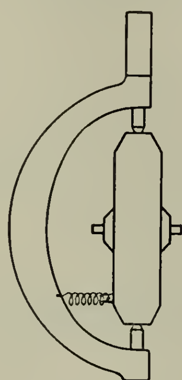
An arrangement of this sort is shown in Fig. 6. The size and

speed of gyro, and the strength of the restoring spring, determine the constants of the equivalent pendulum.

Assume first that the weight of the frame can be neglected in comparison with the gyro.

Let the gyro be of such size and speed that a unit torque about the pivot causes precession at the rate of $p$ radians per second. Let the spring be of such strength that a displacement of the gyro of one radian brings to bear on the gyro a restoring torque $s$. Let the centre of gravity of the system be a distance $c$ below the pivot, and let the mass of the system be $M$.

FIG. 6.



Consider the system initially displaced through a small angle $\phi$, the gyro being in mid position. A torque $Mgc\phi$ acts on the gyro, and it precesses at a rate

$$Mgcp\phi \text{ radians per second.}$$

The spring then exerts a restoring torque

$$s \int Mgcp\phi \, dt$$

and under its influence the gyro precesses about the pivot at a rate

$$Mgscp^2 \int \phi \, dt \text{ radians per second.}$$

That is

$$\frac{d\phi}{dt} = - Mgscp^2 \int \phi dt$$

or

$$\frac{d^2\phi}{dt^2} = - Mgscp^2\phi$$

The pendulum will then oscillate in accordance with the formula

$$\phi = \phi_0 \sin p\sqrt{Mgsc}t$$

If $b$ is the length of the centre of gravity of the equivalent physical pendulum, and $a$ is its radius of gyration we have

$$\sqrt{\frac{gb}{a^2}} = \sqrt{g(Mscp^2)}$$

from which

$$\frac{a^2}{b} = \frac{1}{Mscp^2}$$

Disregarding friction we may then write for the maximum deviation of the pendulum from the vertical when the support is moved harmonically a distance $A$ either side of the centre position

$$\theta max = \frac{A}{\frac{a^2}{b} - \frac{g}{\omega^2}}$$

or

$$\theta max = \frac{A}{\frac{1}{Mscp^2} - \frac{g}{\omega^2}}$$

The rate of precession of a gyroscope is given by

$$\psi = \frac{T}{IV}$$

where

$\psi$ is the angular velocity of precession,
$I$ is the polar moment of inertia of the wheel,
$V$ is the angular velocity of the wheel,

and

$T$ is the applied torque.

Letting

$$T = 1$$

we have

$$p = \frac{1}{IV}$$

from which

$$\frac{a^2}{b} = \frac{I^2V^2}{Msc}$$

and thus

$$\theta max = \frac{A}{\frac{I^2V^2}{Msc} - \frac{g}{\omega^2}}$$

In order to find $a$, assume the pendulum to be hanging vertically, with the gyro in its mid position. Suppose now we apply a torque $T$ to deflect the pendulum from its central position. The gyro first precesses at a rate

$$\psi = \frac{T}{IV} \text{ radians per second,}$$

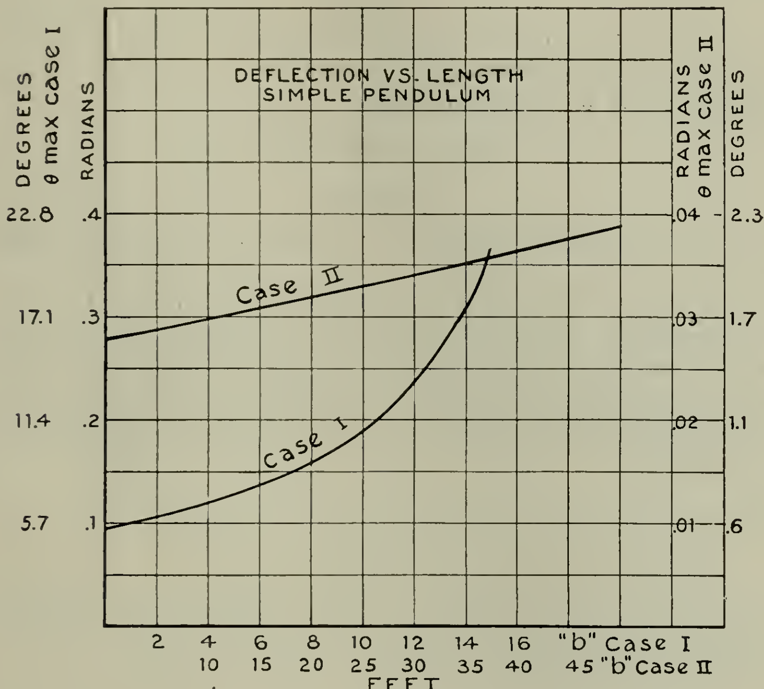
whereupon the restoring spring exerts a restoring torque equal to

$$\frac{sTt}{I^2V^2}$$

which in turn results in a precession in the direction of the applied torque at a rate

$$\frac{sTt}{I^2V^2} \text{ radians per second.}$$

PLATE I.




The angular acceleration is thus

$$\frac{sT}{I^2V^2}$$

If we consider a physical pendulum of mass $M$ and radius of gyration $a$ acted upon by torque $T$, the angular acceleration will be

$$\frac{T}{Ma^2}$$

Hence we have

$$a^2 = \frac{I^2V^2}{sM}$$

and since from the above

$$\frac{a^2}{b} = \frac{I^2 V^2}{sMc}$$

it follows that

$$b = c$$

Thus the effect of the gyroscope is simply to cause the equivalent radius of gyration of the system to be increased to the value

$$a = \frac{IV}{\sqrt{sM}}$$

Usually with gyroscopic stabilizing $\frac{g}{\omega}$ will be so small that only the gyroscopic effect need be considered, and unless $\omega$ is very small we may write approximately

$$\theta max = AMscp^2 = \frac{AMsc}{I^2 V^2}$$

EXAMPLES.

In the following illustrative examples we will consider two cases.

Case No. 1 is intended to be typical of what will be found on smaller boats. The roll is considered regular and 30° each side of the vertical, occurring with a period of five seconds. The instrument is assumed mounted at a distance of 4 feet above the axis about which the craft rolls. We then have in terms of feet and seconds

$$A = 2 \quad \omega = 2\pi .2$$

and

$$x = 2 \sin 1.256t$$

Case No. 2 is intended to represent a large ship. The roll is considered to be 15° either side, with a period of 15 seconds, the instrument mounted 20 feet above the centre of roll.

Then

$$A = 5.2\ , \quad \omega = \frac{2\pi}{15}$$

and

$$x = 5.2 \sin .418t$$

SIMPLE PENDULUM.

Consider first a simple pendulum, and neglect friction. The maximum angle of deviation is given by

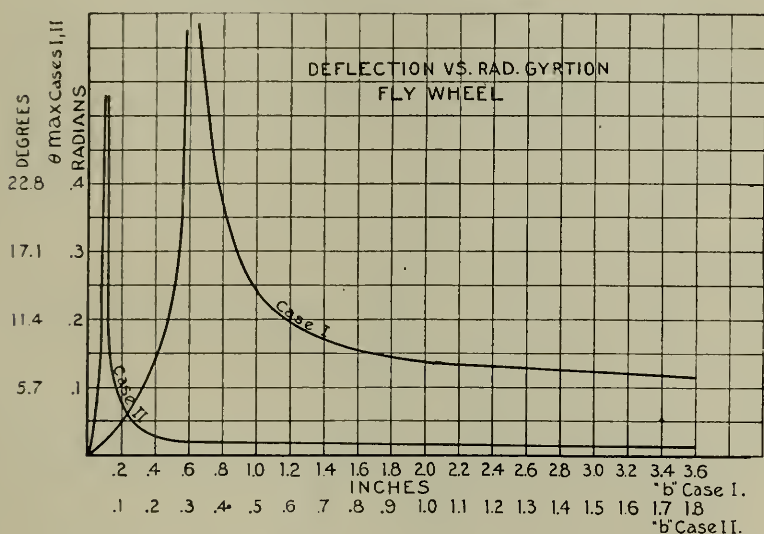
$$\theta max = \frac{A}{b - \frac{g}{\omega^2}}$$

The results of computation for various values of *b* are plotted on Plate I for the two cases above.

The curves show that in Case No. 1 a pendulum of reasonably short length will deflect about 5 degrees while a pendulum 15 feet long will deviate an amount greater than twenty degrees, so much in fact that the formulas no longer hold even approximately.

In Case No. 2 the deflection for a short pendulum will be about 1.5 degrees, this deflection becoming large as the length of pendulum approaches 183 feet.

PLATE II.




This example shows conclusively that a simple pendulum of reasonable length swung in frictionless gimbals on board ship cannot be expected to remain vertical within several degrees.

### PHYSICAL PENDULUM.

As a second example consider a fly wheel with heavy rim swung slightly off centre. Suppose the radius of gyration, which will be approximately the mean radius of the rim, to be 1 foot, and disregard friction.

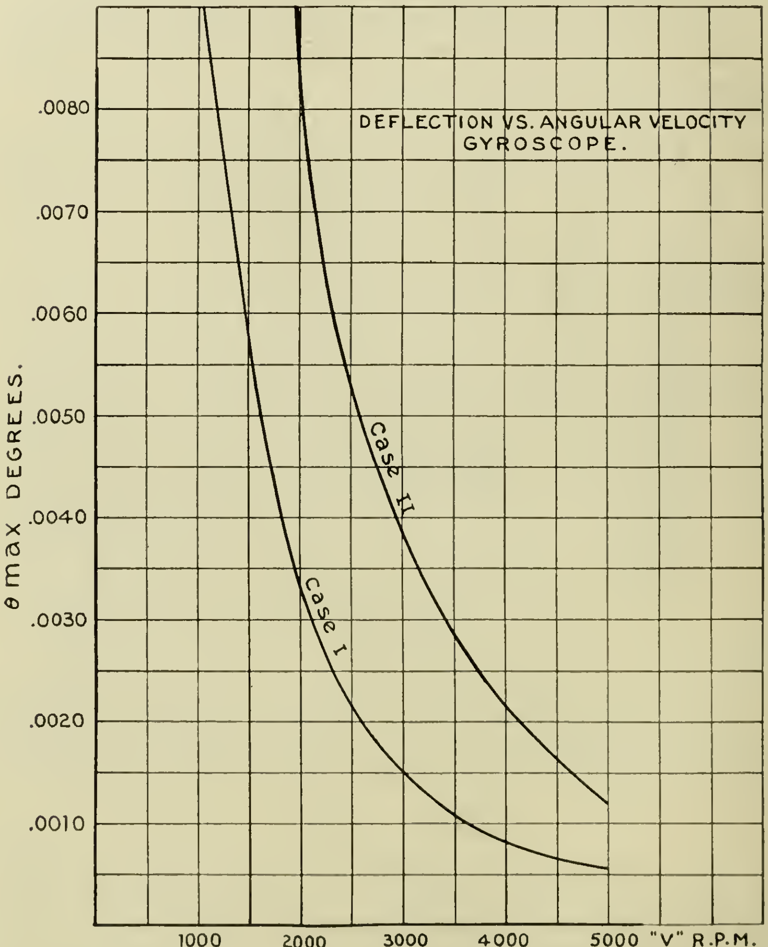
The formula now is

$$\theta_{max} = \frac{A}{\frac{a^2}{b} - \frac{\omega^2}{g}}$$

On curve sheet 2, are plotted the results with this fly wheel suspended various distances off centre.

Considering Case No. 1 we see that when the distance off centre is several inches, the deviation is several degrees, as with

Plate III.




the simple pendulum. If the eccentricity is shortened the angle becomes larger, and at one inch is about 15 degrees. If "*b*" is made very small, however, conditions improve, and when *b* is .12 inches the deflection is 1.4 degrees. If *b* is made .01 inches

the deflection will be in the neighborhood of .1 degree. In this latter case, however, there would not be probably enough eccentricity to properly overcome friction. For Case No. 2 conditions are even less favorable. It will thus be seen that even using a massive pendulum it would be difficult to design in such a manner that very small deflections would result.

### USE OF GYROSCOPE

Let us now consider the use of the gyroscope for stabilizing. Suppose the gyro wheel to weigh 1 pound, with a radius of gyration of .25 feet, revolving at speeds up to 5000 *r. p. m.* Suppose the mass of the whole system to be two pounds, with a centre of gravity .5 feet below the support. Suppose the restoring spring to be of such strength that when the gyro is deflected through 1 radian or 57 degrees it exerts a force of .05 pounds at a lever arm of .1 foot.

Then

$$\begin{aligned} c &= .5 \\ M &= 2 \\ s &= .005 \end{aligned}$$

The formula is

$$\theta max = \frac{A}{\frac{I^2 V^2}{Msc} - \frac{g}{\omega^2}}$$

and for the values of the example:

Case No. 1

$$\theta max = \frac{2}{.78\, V^2 - 20.4}$$

Case No. 2

$$\theta max = \frac{5.2}{.78\, V^2 - 183.6}$$

On Plate III are plotted curves for this example for speeds up to 5000 *r. p. m.*, that is up to

$$V = \frac{2\,\pi\, 5000}{60} = 524 \text{ radians per second.}$$

It will be noted that at this highest speed the maximum deflection in the two cases is .0005 and .0014 degrees, respectively. Thus practically complete stabilization is obtained.

MEDFORD HILLSIDE, MASS.,
Nov. 8, 1918.

**Hydro-Electric Development in Ontario.** (*The Canadian Engineer,* vol. xxxvi, p. 529, June 12, 1919.)—Sixty thousand horsepower will be developed on the Nipigon River, about sixty miles northeast of Port Arthur, by the Hydro-Electric Commission of Ontario, and it is expected that by June of next year two 12,000 h.p. units will be in operation. Propositions from several leading water turbine builders are now being considered, and after the contract for the " wheels " is let, which may be within the next two or three weeks, definite plans will be completed and active work will be commenced at the site of the new power house.

The Nipigon River flows from Lake Nipigon to Lake Superior, a distance of about 32 miles. The normal elevation of Lake Nipigon is 852 ft., and of Lake Superior, 602 ft. There are at least four power sites on the river, all of which will ultimately be developed by the Commission. Between Lake Nipigon and Emma Lake are Virgin Falls, Rabbit Rapids and Devil Rapids, where the total head for development through Hannah Lake would be 42 ft. South of Emma Lake are Flat Rock Rapids, White Chute and Pine Portage Rapids, with a head of 55 ft. South of Lakes Maria and Jessie—near Cameron's Pool—are two sites. The upper site affords 65 ft. net head and the lower, 53 ft. The upper site at Cameron's Pool is considered to be the most advantageous one on the river, and naturally will be developed first.

The design of the proposed plant includes a regulating dam that can raise the river level to the elevation of Lakes Maria and Jessie, which will form natural storage reservoirs. It is estimated that a peak load of 60,000 h.p. can be taken care of by the normal flow, and that is the size of the plant that will be built.

The initial installation will be two units, each 12,000 h.p., but three more will be installed at a later date. Single runner vertical water turbines will be direct-connected to 3-phase, 60-cycle, 12,000-volt, internal revolving field generators, each 10,600 k.v.a. (80 per cent. factor, maximum rating). The generators will be arranged for parallel operation and will supply light, heat and industrial power on the Commission's " Nipigon System." This development is further west than any other yet undertaken by the Commission.

# THE PHOTOMETRIC SCALE.*

BY

HERBERT E. IVES, Ph.D.

Member of the Institute.

## INTRODUCTORY.

The term "Photometric Scale" is here used to include, in reference to photometry, the same kind of collection of constants, fixed points, methods, etc., as, in reference to thermometry, go to establish and maintain the thermometric or temperature scale. Such a scale, rationally based, and adequately specified, is necessary in any branch of exact science, to insure agreement of results among different workers, and to give their results scientific and practical value when obtained.

A complete photometric scale has been established and published by the present writer during the past few years. It involves the following factors:

1. Conditions of observation.
2. Method of choosing observers.
3. Relative luminous values of radiant energy of various wave-lengths.
4. The value of the lumen in terms of the watt of luminous flux.
5. Standards of luminous intensity.
6. Standards of color difference.

These factors have been interchecked until complete agreement and consistency have been obtained—an essential procedure if photometric methods are to be used in accurate scientific work. As the scale now stands it provides complete and practical means for the precision measurement of the luminous values of all kinds of light sources.

Since its first publication a number of years have elapsed, in which time additional data have been collected, both by the writer and by others (notably at the Bureau of Standards), which now make it possible to fix the constants of the scale with somewhat greater exactness. It is the purpose of the present article to gather together in one place all the recommendations and data which constitute this scale, bringing them completely up to date.[1]

* Communicated by the Author.

### I. CONDITIONS OF OBSERVATION.

Since the relative luminosity of the various colors is a continuously varying function of brightness and field size, it becomes necessary to choose certain conditions as standard conditions of measurement. The brightness and field size selected should be representative of useful working conditions. The measuring method should be a practical one, of as high precision as possible.

As a result of comprehensive studies the writer [2] has been led to recommend the use of a field brightness of 2.5 milli-lamberts, and a field size of two degrees diameter. This brightness is about as high as can be easily handled with the photometric standards in ordinary laboratory use. It is, however, at the lower limit of modern working illuminations, and considerably below normal daylight illuminations. This latter objection is offset by the use of the small field, which has the effect of shifting the equivalent illumination upward, so that the final condition does correspond to modern working illuminations.

A very great advantage of the choice of these conditions is that under them the extremely practical and precise flicker photometer yields (at infinitely less trouble) the same results as are derived from the less precise method of juxtaposed fields or direct comparison.[3]

The complete specifications for the conditions of observation for precision photometry on the scale under discussion are then:

*A photometric field of two degrees diameter, a field brightness of* 2.5 *milli-lamberts.* (A)

*The use of the flicker photometer is recommended.*[4]

### II. METHOD OF CHOOSING OBSERVERS.

No agreement between different laboratories, nor useful photometric results corresponding to an average eye, can be obtained without some standardized method of picking observers whose color vision is normal or averages normal. The ideal method of choosing observers would be to obtain the luminous efficiency curve of the spectrum for each member of the laboratory staff, and pick the men to be used by comparison with an established average luminous efficiency curve. The labor involved in such a procedure makes it, however, impracticable for general use.

As an alternative simpler method, the author has proposed [5] the measurement by each prospective observer of an arbitrary

color difference whose value for the average eye has been established by numerous observations. Only those observers should be used who are normal, or who form a group which averages normal.

The color difference proposed was that furnished by placing over a "4-watt" carbon lamp two inorganic salt solutions in layers one centimetre thick, whose composition was such that the absorptions were equal for the average eye. The group to be used in any color difference measurement was then such a group that their average reading of the two solution transmissions was equality.

The original solutions were worked out on the basis of measurements made on 61 observers. At a later date, Crittenden and Richtmyer at the Bureau of Standards [6] made measurements upon about double this number of observers, and as a result found a slight change necessary in the ratio of transmissions. This in turn indicated a change of composition in order to give two solutions of equal transmission. Making this change in composition, the method of choosing observers may now be specified as follows:

*Observers for making color difference comparisons shall be selecetd by measurements on two test colors. The constitution of the YELLOW test color is*

*72 grams potassium bichromate to one litre of water. The constitution of the BLUE test color is*

*57 grams copper sulphate to one litre of water.*

*The group of observers, preferably not less than five in number, should obtain an average value of unity for the ratio of the transmissions of these test color solutions when used over a "4-watt" carbon lamp.* (B)

Details as to the technic of preparing the solutions, the choice of tanks, and the temperature coefficients, may be obtained from the original publications.[7, 8]

## III. RELATIVE LUMINOUS VALUE OF RADIANT ENERGY OF VARIOUS WAVE-LENGTHS.

An essential part of the photometric scale is the relation between radiant energy and luminous energy, for all colors, or the *luminous efficiency curve of the spectrum.* Only by an exact knowledge of this can light and energy be coördinated, and photometry become a really precise branch of science. It should be

self-evident that the luminous efficiency curve must be obtained by the same photometric method as is used in the photometry of the integrated luminous fluxes.

In the scale as published by the writer the luminous efficiency curve was arrived at by empirical variation of a curve obtained by direct measurement with a limited number of observers. The

TABLE I.

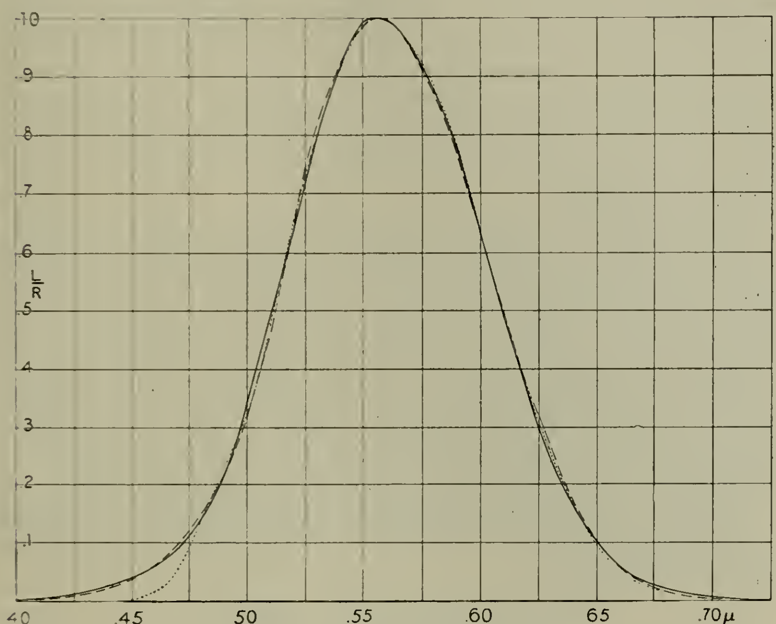
*Luminous Efficiency of the Spectrum.*

| $\lambda$ | Physical Photometer | Nutting | Calculated (3-Term Expression) |
|---|---|---|---|
| .400$\mu$ | .... | .0021 | .0024 |
| .410 | .... | .0036 | .0032 |
| .420 | .... | .0065 | .0096 |
| .430 | .... | .0115 | .018 |
| .440 | .... | .022 | .029 |
| .450 | .... | .038 | .041 |
| .460 | (.007) | .061 | .058 |
| .47c | (.029) | .101 | .090 |
| .480 | (.091) | .149 | .138 |
| .490 | (.185) | .215 | .215 |
| .500 | .317 | .314 | .341 |
| .510 | .478 | .456 | .493 |
| .520 | .652 | .646 | .638 |
| .530 | .799 | .815 | .795 |
| .540 | .911 | .925 | .919 |
| .550 | .985 | .986 | .992 |
| .560 | .999 | .995 | .999 |
| .570 | .957 | .949 | .953 |
| .580 | .888 | .871 | .879 |
| .590 | .782 | .762 | .777 |
| .600 | .639 | .634 | .633 |
| .610 | .494 | .498 | .491 |
| .620 | .365 | .368 | .362 |
| .630 | .261 | .268 | .240 |
| .640 | .170 | .166 | .164 |
| .650 | .094 | .105 | .101 |
| .660 | .051 | .058 | .060 |
| .670 | .029 | .032 | .038 |
| .680 | .014 | .016 | .022 |
| .690 | .008 | .0c81 | .013 |
| .700 | .... | .0036 | .007 |

variations were made in the constitution of a " luminosity curve solution " used with a non-selective radiometer to form a precision physical photometer, and the modified curve was checked by measurements on the " test colors " and on a large range of black body colors, until it gave results completely agreeing with the visual method.

With the slight change of composition made necessary in the test color solutions by the measurements on a larger number of observers, a corresponding change was called for in the luminous efficiency curve. This was made by an empirical change in the composition of the physical photometer solution, and published some time since,[9] without, however, any figures on the spectral character of the change resulting.

FIG. 1.




Luminous efficiency of the spectrum.

Dotted line—Physical photometer solution.
Dashed line—Nutting's curve as revised.
Full line—Calculated from 3-term expression.

There has recently been made, through the courtesy of the Bureau of Standards, a precision measurement of the spectral transmission of this revised luminous efficiency curve solution. This measurement was made by both visual and photo-electric spectroradiometry, and is probably considerably more accurate, especially at the blue end of the spectrum, than the measurements made and published on the earlier solutions. The results of this measurement are listed in Table I, and are plotted (dotted line) in Fig. 1.

In comparing this with the earlier curve (which lies further toward the red) and with other published curves, the interesting fact was discovered that it almost exactly agrees with the one obtained by Doctor Nutting some years ago, using substantially the photometric method here outlined, although with a random group of 21 observers. Nutting's curve as originally published did not prove suitable as tested on the physical photometer,[10] but it has since been revised as the result of later data on the energy distribution of the light source used, and it is this revision which (kindly furnished by Doctor Nutting), as shown by the dashed curve in Fig. 1, is practically coincident with the lately obtained luminous efficiency curve solution transmission. The difference in the blue is to be decided in favor of Nutting's curve, since the physical photometer tests would be inadequate to detect a deficiency of this sort.

The significance of this agreement is that each curve supplements the other. Nutting's curve was obtained with a group of observers whose characteristics are not known in terms of the test colors, so that while its shape and end characteristics are well established, its position in the spectrum may be shifted from the average of a larger group. On the other hand, the physical photometer solution is accurately coördinated with the test colors, but its shape and characteristics at the ends of the spectrum (particularly the blue) might be only approximately right.[11]

It has been shown by Kingsbury [12] that the luminous efficiency curve of the spectrum may be well represented by a series of terms of the form

$$\frac{L}{R} = \left(\frac{\lambda max}{\lambda}\right)^n e^{n\left(1 - \frac{\lambda max}{\lambda}\right)}$$

Both of the curves under discussion are well represented by a three-term expression of this form with constants given below. As a consequence the formulation of the relation between the luminous values and the energy values of the spectrum may be expressed as follows:

*The luminous efficiency curve of the spectrum is given by the expression* (C)

$$\left(\frac{L}{R}\right)_\lambda = .977\left(\frac{.556}{\lambda}e^{1-\frac{.556}{\lambda}}\right)^{200} + .085\left(\frac{.60}{\lambda}e^{1-\frac{.60}{\lambda}}\right)^{1300} +$$

$$.04\left(\frac{.47}{\lambda}e^{1-\frac{.47}{\lambda}}\right)^{200}$$

*The luminous efficiency curve of the spectrum is accurately copied for purposes of physical photometry by a solution of composition* (D)

| | |
|---|---|
| $Cu\ Cl_2$ .................................................. | 61.25 grams |
| $Co\ (NH_4)_2\ (SO_4)_2$ ................................ | 14.5 grams |
| $K_2\ Cr\ O_4$ ............................................ | 1.9 grams |
| Water to ............................................... | 1 liter |

The original paper [10] should be consulted for details of the technic of the physical photometer.

### IV. THE VALUE OF THE LUMEN IN TERMS OF THE WATT OF LUMINOUS FLUX.

The common unit of luminous flux, the lumen, is entirely arbitrary.[13] It is related to the watt of luminous flux by a constant, commonly called "the mechanical equivalent of light." The simplest method of obtaining the value of this constant is to measure in absolute units the energy transmitted by a luminous efficiency curve screen from a light source of known lumen output. This measurement has been carried through with the original luminous efficiency curve solution, giving a value for the lumen of .00160 watts. In order to correct this to the newer curve it has only been necessary to obtain the luminosity curve of a standard ("4-watt") lamp for both curves, which is easily done graphically, and measure the relative areas. Carrying through this procedure gives as the new figure .00156. The next element of the photometric scale is therefore specified as follows:

*The lumen is equivalent to* .00156 *watts of luminous flux.* (E)

### V. STANDARDS OF LUMINOUS INTENSITY.

The question of a primary standard of light assumes somewhat less importance than has been accorded to it in the past, immediately luminous flux is properly analyzed into its physical part and its physiological part. The rational *unit* of luminous flux, the watt, is to be maintained by the same standards as those employed for the measurement of any form of radiant energy. *Any* light source is giving unit illumination when its radiation measured on the far side of a luminous efficiency curve screen is of unit value.

As a matter of convenience, however, it is desirable to have certain *fixed points* or standards, by which the value of the unit may be obtained at any time without going through all the steps

requisite for its original establishment. In the case of light the fixed point presenting the greatest merit is the black body at the melting point of platinum. Its exact value is still subject to refinement of determination, but as a result of the most recent measurement [14] the following specification may be given:

*As a standard fixed point in photometry the brightness of the black body at the melting point of platinum may be adopted as* 58.35 *candles per square centimetre.* (F)

### VI. STANDARDS OF COLOR DIFFERENCE.

In the interest of economy of labor, it is desirable to embody the results of measurements carried out under the most elaborate standard conditions, in subsidiary standards. In the case of color difference photometry the subsidiary standards take the form of illuminants of different color, or colored media, whose characteristics are reproducible and have been made the subject of measurement and specification.

In order to have such standards to meet all contingencies it would obviously be necessary to have sub-standards of an enormous number of colors, and in the course of time it is, in fact, likely that the number of color difference standards prepared for use with different illuminants will become quite large. Up to the present, however, the only standards of this sort that have been developed are for the most commonly occurring type of color difference in ordinary illuminants, namely, the black body series.

The set of such standards belonging to the photometric scale under discussion consists of a yellow and a blue solution, made up in conformity with the suggestion of Professor Fabry, of such spectral character of absorption that increasing differences of color along the black body scale are met by increased concentrations.[15] The composition of these solutions is given below. The transmissions were measured, at the time of the publication of the composition, in terms of the group of observers available at that time, and it is to be expected that the somewhat altered scale due to the greater number of observers now embodied would alter the values. As a matter of fact, however, measurements made by Crittenden and Richtmyer [6] on one of these solutions show the original calibration to hold even with the larger group of observers. This is to be ascribed to the fact that the color differ-

ences involved are much less than those of the "test colors," in whose value occurred a difference of only two per cent. Until, therefore, more refined measurements dictate a revision of the Fabry solution values, these stand as in the original publications. They are embodied in the following:

*A yellow absorbing solution for use with color differences of the black body type is composed of*

| | | |
|---|---|---|
| Cobalt ammonium sulphate ........................ | 100 | grams |
| Potassium dichromate ............................. | .733 | grams |
| Nitric acid (1.05 gr.) ............................ | 10 | c.c. |
| Water to ........................................... | 1 | liter |

*Its transmission in a thickness of one centimetre as compared with clear water is given by the formulæ,*

$\log_{10} T = -0.245\, C^{0.9}$—when used over a "4 watt" lamp.

$\log_{10} T = +0.366\, C^{1.05}$ — when used over a test lamp to bring the light to "4 watt" color.

where $c$ is concentration ........................................... (G)

*A blue-absorbing solution for use with color differences of the black body type is composed of*

| | |
|---|---|
| Nickel ammonium sulphate ................ | 50 grams |
| Ammonium sulphate ........................ | 10 grams |
| Ammonia 0.90 gr. ......................... | 55 c.c. |
| Water to .................................. | 1 liter of solution. |

Dilute with water containing 10 gr. ammonium sulphate per liter.

*Its transmission in a thickness of one centimetre as compared with clear water is given by the formula* (H)

$\log_{10} T = -0.539\, C^{1.03}$ — when used over a "4 watt" lamp.

Details as to technic, temperature coefficients, etc., are to be found in the original publications.[15, 16]

## VII. DISCUSSION.

The system of photometry which is here summarized will appear to many to be a complicated and difficult one. It is to be remembered, however, that complexity is inherent in any complete scheme for color difference photometry, both because of the nature of color vision in the individual, and because of the statistical element which enters due to the varying characteristics between individuals. Considered from this standpoint it is believed the system is in reality as simple as an adequate one can be.

made. It may be emphasized that it is the *only* complete system thus far presented. It is further to be remembered that it is not the intention that the complete photometric procedure be gone through with every measurement, or in every laboratory. The ideal is to use the method for the establishment of secondary standards, by means of which all practical photometry is carried out with no color differences, leaving the fundamental color difference measurements to be made in the standardizing laboratories.

NOTES.

[1] This paper may be considered as a revision to date of portions of the communication "Proposals Relative to Definitions, Standards and Photometric Methods," presented to the Illuminating Engineering Society, May, 1915.

[2] *Philosophical Magazine,* July, September, November, December, 1912, pp. 149, 352, 744, 845, 853.

[3] The identity of the results given by the two methods *under the conditions specified, and on the employment of enough observers* to secure a significant average from the widely scattering values apt to be obtained in the juxtaposed field comparison, is a fact of experiment against which no conflicting evidence has been adduced. It has, on the other hand, been confirmed by the work of Abney and Watson, and by the extensive study of Richtmyer and Crittenden at the Bureau of Standards. It is not claimed by the writer, and never has been, that the two methods give the same results under other conditions. It was, in fact, his own researches which first showed in what manner and to what extent the two methods give different results. It is consequently quite beside the point for critics to attempt to discredit the photometric scale under discussion by blanket assertions that "*the* flicker method" gives results different from "*the* equality of brightness method." Such criticism is on a par with attempting to discredit accurate methods of linear measurement by stating that a bar of lead and a bar of platinum measured at 0° are of unequal lengths at any other temperature. The necessity for recourse to standard comparison conditions, due to the fact that response to varying conditions is different in different substances, is not peculiar to heterochromatic photometry. A red light and a blue light cannot, from the nature of vision, be equal under all conditions, and the choice of comparison conditions after a thorough consideration of the questions of utility, practicability and convenience, is entirely on a par with procedure in other departments of measuring science.

[4] There appears to be prevalent an idea that "ordinary photometry" and "the conditions of ordinary photometry" stand upon a firm basis, that they are sacrosanct, immutable, and in fact give exactly the measurements required for the proper evaluation of all light quantities. As a matter of fact there is no basis whatever for such a belief. "The conditions of ordinary photometry" are to a predominant degree accidental. They have not to this day been made the subject of definite specification, and have never, previous to the writer's researches, been studied quantitatively at all with reference to the phenomena of color perception. The only requirement for "ordinary photom-

etry" (which is photometry in which *no color difference is present*), is the use of a sufficient field brightness and size to bring the observations into the region of respectable precision of setting, when the eye is the null radiometer employed. The most common conditions (in American practice) are an illumination of about 10 metre candles (near the lower limit of the region of good photometric precision), and a field of about 5 degrees diameter. The former condition is directly traceable to the candlepower and physical dimensions of the light sources and standards in common use a decade or two ago; the latter probably is connected with the size of prism which it was originally found practicable to grind to the Lummer-Brodhun form. But neither condition is authoritatively specified or generally adhered to. As long as there is no color difference present it is unnecessary to hold to narrow conditions. In fact had the thermopile been as sensitive and as practical in form thirty years ago as now, it is not beyond the bounds of possibility that it would have been seriously advocated as a photometer, for which purpose it would have been entirely suitable, as long as no difference of color existed between the light sources under comparison. The error of using "the conditions of ordinary photometry" for colored light comparison is of the same nature, even though not as great, as is the use of a thermopile. It is inevitable that when color differences are to be compared a narrower and more exact choice of conditions must be made than sufficed formerly. It would have been entirely an accident had the "conditions of ordinary photometry" (such as they are) been identical with those dictated by a basic study of the heterochromatic problem.

It must not be overlooked by those who display concern for "ordinary photometry" that the conditions here specified for color difference photometry yield identical results to "ordinary photometry" for the only measurements for which the latter was ever suited, so that there is nothing revolutionary involved in picking conditions suited to color difference photometry. The adoption of definitely specified conditions is a step inseparable from the advance of any science. The "eye of the skilled workman" has had to yield to the pyrometer in heat measurement, and in photometry the "practiced observer" must yield to a well-considered and definitely specified photometric procedure.

[5] *Trans. Illum. Eng. Soc.*, x, No. 3, 1915.

[6] *Bull. Bur. Stds.* 14, 87, 1918.

[7] *Trans. Ill. Eng. Soc.* viii, p. 795, 1914; *Trans. Ill. Eng. Soc.*, p. 253, 1915.

[8] The method of measurement, and the method of choosing observers, as here specified, are those now in use at the Bureau of Standards.

[9] JOURNAL FRANKLIN INSTITUTE, July, 1918, p. 121.

[10] *Physical Rev.*, Nov., 1915, p. 319.

[11] Two other comparatively recent determinations of the luminous efficiency curve of the spectrum are not included for consideration because they were not made under the conditions which fix the photometric scale under discussion. The extensive investigation of Coblentz (*Bull. Bur. Standards* 303, Sept. 12, 1917, p. 168), although stated to be carried out in accordance with the procedure of the present writer, was not, in the vital particular of field brightness, which was not over one-quarter that here specified. As a conse-

quence the curve obtained by him is shifted toward the red. An experimental test of Coblentz's luminosity curve solution, based on his determination of the luminous efficiency curve, shows an error on the test colors of 4½ per cent. (JOURNAL FRANKLIN INSTITUTE, July, 1918, p. 121). The determination by Hyde, Cady and Forsythe (*Astrophysical Jour.*, Sept., 1918, p. 65) was made by the cascade method, which the writer had already shown would give the same results as the flicker method under the small field high brightness conditions specified by him. The investigators quoted, however, carried through their work under conditions of brightness and field size (the latter not specified) supposed to correspond to "the conditions of ordinary photometry." which as already pointed out, have no rational basis for use in color difference comparisons. As a consequence of their use of these conditions their curve is shifted toward the blue, as compared with the one here given. Neither Coblentz's nor Hyde's curves are coördinated with any accurately specified observing conditions nor method of choosing observers. They constitute isolated elements of photometric scales which are not only incomplete but without sound bases for adoption even if supplied with their missing parts.

[12] *Physical Rev.*, Feb., 1916, p. 161.

[13] See JOURNAL FRANKLIN INSTITUTE, Oct., 1915, p. 409.

[14] JOURNAL FRANKLIN INSTITUTE, July, 1918, p. 122.

[15] *Trans. Ill. Eng. Soc.*, p. 796, 1914; *Trans. Ill. Eng. Soc.*, p. 253, 1915.

[16] The only other color difference standards of a reproducible nature thus far published are furnished by the tungsten lamp characteristic equations of Middlekauff and Skogland (*Bull. Bureau Standards*, No. 238, p. 483, Oct., 1914). Their validity is conditioned by the uniformity of characteristics from one lamp to another, which is hard to guarantee in so complicated a product as the modern incandescent lamp. Moreover, the equations as published are based on photometric measurements carried out under conditions and with observers neither of which were the subject of study or selection, or of specification. It is understood that a revision of these equations is contemplated, based on photometric determinations made on the scale here described.

## APPENDIX.

### APPLICATION TO THE BLACK BODY.

THE luminous efficiency curve of the spectrum may be applied (due to the possibility of summating luminous radiations) to the calculation of the luminous characteristics of any radiation of known physical constitution and intensity. The most important case is the black body, or complete radiator. Luminous efficiency curve equations of the form above given may be combined with the Planck black body energy distribution equation and integrated to give the luminous radiation, in ergs or watts of luminous flux. From this, upon division by the constant relating the number of

watts of luminous flux to the lumen (mechanical equivalent of light), the flux, or brightness, may be immediately derived in the ordinary units of lumen and candlepower.

The form and derivation of these equations has been given by Kingsbury.[1] In re-calculating them for the new luminosity data here presented several deviations have been made from the previous procedure. As given by Kingsbury the constants are all worked out numerically, on the basis of a chosen value of the black body constant $c_2$, (14370). Experience in being forced to recalculate the data to several other temporarily more popular values of the constants, or to values which would make possible a real comparison of work of different observers, has suggested the desirability of stating the equations in such form that the place of occurrence of all the black body constants shows clearly. This, in turn, is but the first step in the search for a mode of expressing the luminous flux equations in which the calculations once made and tabulated will be independent of any particular choice of the black body constants. While the uncertainties in the values of these constants are becoming gratifyingly small, they still amount to a great deal when translated into terms of luminosity; and the refinements yet to be made in their determination will be important factors in their use in luminous flux equations. The desired form of the luminous flux equations, into which the latest and best values of the constants can be introduced at any time, is furnished by taking advantage of the fact that the two variables, *shape of the emission curve* (determined by $\frac{C_2}{T}$) and *luminous efficiency* (ratio of the light-evaluated to the total energy), are connected by definite values which may be calculated without assuming definite figures for the black body constants. Accordingly the data herewith plotted are values of $\frac{L}{R}$ (where $L$ is the light-evaluated, $R$ the total radiant energy), against $\frac{C_2}{T}$.

Expressed in this new form the flux equation as developed by Kingsbury becomes

$$\frac{L}{R} = \left(\frac{c_2}{T}\right)^4 \times .01922 \left[\sum p \frac{\frac{1}{\sqrt{n}}\left(\frac{n+3}{n}\right)^{n+\frac{7}{2}}}{\lambda_m^4\left(\frac{1}{n\lambda_m}\frac{c_2}{T}+1\right)^{n+4}}\right] \tag{1}$$

Upon introducing the constants of the luminous efficiency curve equation as developed in the body of the paper this equation becomes

$$\frac{L}{R}=\left(\frac{c_2}{T}\right)^4\left[\frac{.28730}{\left(.008993\frac{c_2}{T}+1\right)^{204}}+\frac{.0070326}{\left(.001282\frac{c_2}{T}+1\right)^{1304}}+\frac{.022581}{\left(.01064\frac{c_2}{T}+1\right)^{204}}\right) \tag{2}$$

TABLE I.

*Black Body Luminous Characteristics.*

| $\frac{C_2}{T}$ | $\frac{L}{R}$ | $Log_{10}\frac{L}{R}$ | $\lambda_e$ |
|---|---|---|---|
| 1 | .0514 | $\bar{2}.71096$ | .546μ |
| 2 | .1296 | $\bar{1}.11261$ | .5515 |
| 3 | .1085 | $\bar{1}.03551$ | .5575 |
| 4 | .05755 | $\bar{2}.76102$ | .5635 |
| 5 | .02416 | $\bar{2}.38303$ | .569 |
| 6 | .008778 | $\bar{3}.94340$ | .5745 |
| 7 | .002864 | $\bar{3}.45697$ | .5795 |
| 8 | .0008768 | $\bar{4}.94290$ | .5845 |
| 9 | .0002479 | $\bar{4}.39435$ | .5895 |
| 10 | .00007198 | $\bar{5}.85721$ | .5945 |
| 11 | .00001994 | $\bar{5}.29937$ | .5995 |
| 12 | .000005217 | $\bar{6}.71740$ | .604 |

Calculated values, using this equation are listed in Table I and plotted (in terms of the logarithm of $\frac{L}{R}$), in Fig. 1.

In order to arrive at definite values of luminous flux it is, of course, necessary to choose and introduce definite values for the black body constants. Thus to obtain $L$, the luminous flux in watts, we use the relation

$$L=\left(\frac{L}{R}\right)\times\sigma\, T^4 \tag{3}$$

To obtain the normal flux $L_0$, we use the equation

$$L_0=\left(\frac{L}{R}\right)\times\frac{\sigma\, T^4}{\pi} \tag{4}$$

To transform these results to lumens and candlepower we divide by $m$, the watts of luminous flux in the lumen, thus

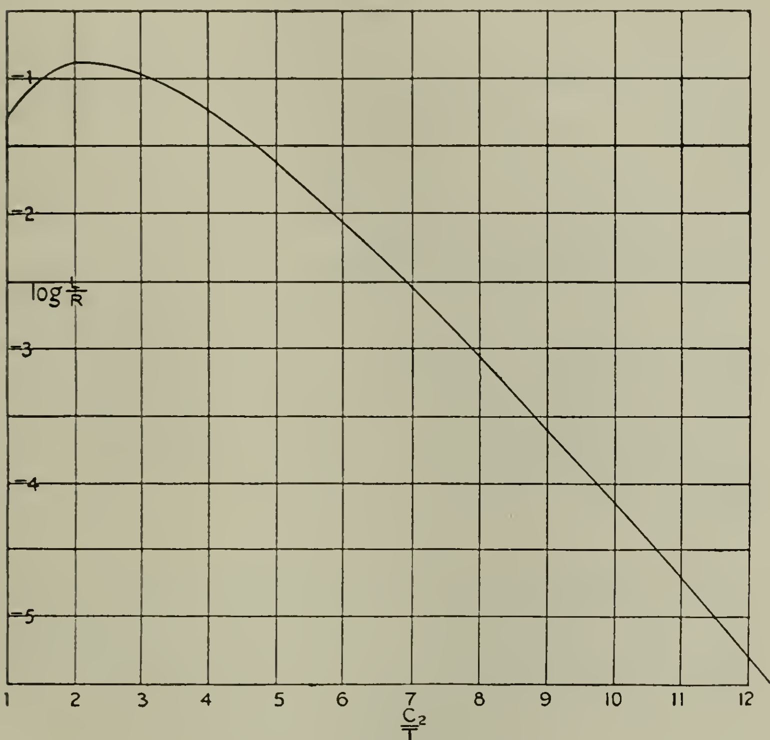
$$F=\left(\frac{L}{R}\right)\times\frac{\sigma\, T^4}{m} \tag{5}$$

$$F_0=b=\left(\frac{L}{R}\right)\times\frac{\sigma\, T^4}{\pi\, m} \tag{6}$$

Some illustrations of the use of these equations are of interest. Two characteristic ones are furnished by the luminous properties of the black body at the melting points of gold and platinum respectively:

Assuming Millikan's values for the black body constants, we have for gold, with its well-established melting point of 1336° K.,

FIG. 1.




Luminous efficiency of the black body.

the value $\frac{14312}{1336} = 10.7125$ for $\frac{C_2}{T}$. Using this in (2) we obtain for $\frac{L}{R}$ the figure .000000002172. From (4), taking $5.72 \times 10^{-12}$ for $\sigma$ we obtain for $L_0$ the value .0001659. Dividing this by .00156, the value chosen in the body of the paper for $m$, we finally get for the brightness of the black body at this temperature,—

0.1062 candles per square centimetre.

The latest determination of this quantity is that of Holst

and Visser.[2] Their value is 0.1071. Details of their photometric method are not at present available, so that the accuracy with which it is represented by the luminous efficiency curve here chosen is problematical. Furthermore, it is to be noted that the calculated brightness varies with enormous rapidity [3] with the choice of $c_2$. On the whole, therefore, the agreement of calculated and observed values to within one per cent. is excellent.

In the case of platinum, if we take the same black body constants, together with the latest value for the melting point, namely, 2037° K., the result for the brightness is 55.9 candles per square centimetre. Experimental determinations by the writer [4] gave this quantity as 58.35. This leaves a discrepancy of four per cent., which, however, is quite as likely to be due to uncertainty in the melting point of platinum, and in the value of $c_2$, as in the photometric method and calculations.

It is evident from these calculations, applied in the one case to a region where photometric observation is reaching its lower limit of feasibility, in the other to a region where exact temperatures are still in question, that the photometric methods and equations are in very practical shape for use. In the form they are here presented they will be available for calculations of the highest precision immediately the constants of the black body are fixed.

A second quantity of interest in connection with the luminous properties of the black body is the *equivalent wave-length* or the wave-length at which the rate of energy emission is varying with change of temperature at the same speed as the rate of luminous emission changes. (The equivalent wave-length, which applies to *one* temperature, is to be distinguished from the *Crova wave-length,* which is the wave-length to be used in comparing emissions due to *two* different temperatures. To a close approximation the Crova wave-length is the mean of the equivalent wave-lengths.)

Expressing the equations derived by Kingsbury [1] for the equivalent wave-length in terms of the more convenient variables $\frac{C_2}{T}$ and $\frac{L}{R}$ we get

$$\lambda_e = \frac{\sum p \dfrac{\dfrac{1}{\sqrt{n}}\left(\dfrac{n+3}{n}\right)^{n+\frac{7}{2}}}{\lambda_m^4\left(\dfrac{1}{n\lambda_m}\dfrac{C_2}{T}+1\right)^{n+1}}}{\sum p \dfrac{\dfrac{1}{\sqrt{n}}\left(\dfrac{n+3}{n}\right)^{n+\frac{7}{2}}\left(\dfrac{n+4}{n}\right)}{\lambda_m^5\left(\dfrac{1}{n\lambda_m}\dfrac{C_2}{T}+1\right)^{n+5}}} = \frac{\dfrac{L}{R}}{\left(\dfrac{C_2}{T}\right)^4 \times .01922 \times \left[\sum p \dfrac{\dfrac{1}{\sqrt{n}}\left(\dfrac{n+3}{n}\right)^{n+\frac{7}{2}}\left(\dfrac{n+4}{n}\right)}{\lambda_m^5\left(\dfrac{1}{n\lambda_m}\dfrac{C_2}{T}+1\right)^{n+5}} + \right]} \qquad (7)$$

Introducing the numerical values derived from the luminosity curve equation, this becomes

$$\lambda_e = \frac{\dfrac{L}{R}}{\left(\dfrac{C_2}{T}\right)^4 \times \left[\dfrac{.52708}{\left(.008993\,\dfrac{C_2}{T}+1\right)^{205}} + \dfrac{.011757}{\left(.001282\,\dfrac{C_2}{T}+1\right)^{1305}} + \dfrac{.049244}{\left(.01064\,\dfrac{C_2}{T}+1\right)^{205}}\right]} \qquad (8)$$

Values calculated from (8) are given in Table I, and are plotted in Fig. 2.

The plotted values of $\lambda_e$ lie on a smooth curve, which is represented with considerable accuracy by an equation of the form

$$\lambda e = a + b\left(\frac{C_2}{T}\right) + c\left(\frac{C_2}{T}\right)^2 \qquad (9)$$

Solving for the constants we find the following numerical equation to represent the curve well,

$$\lambda e = .5402 + .0062\left(\frac{C_2}{T}\right) - .000074\left(\frac{C_2}{T}\right)^2 \qquad (10)$$

It has been pointed out by Foote [5] that an equation of this form may be made the basis of an empirical luminous flux equation of comparatively simple form for numerical calculation. In order to form such an equation in terms of $\frac{C}{T}$ and $\frac{L}{R}$ we note

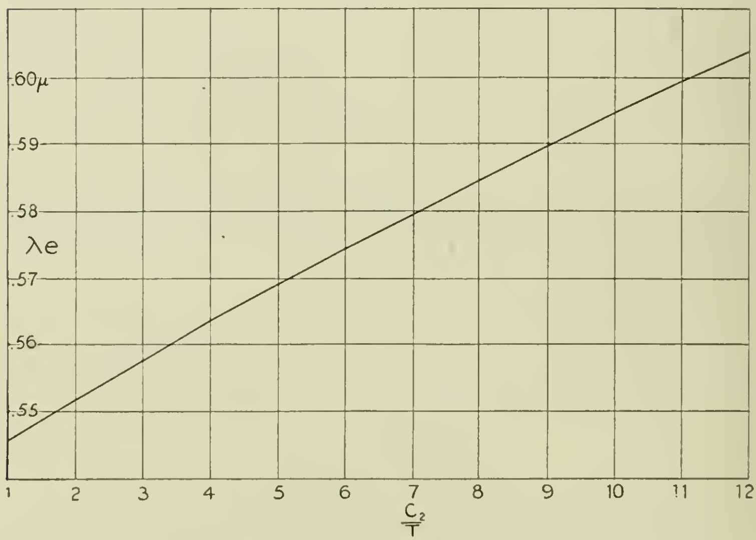
that if the luminous radiation is considered as monochromatic we may represent it by the expression

$$L = c_1'\lambda^{-5} e^{-\frac{c_2}{\lambda T}} \tag{11}$$

and $\frac{L}{R}$ by the expression

$$\frac{L}{R} = c_1'\lambda^{-5} e^{-\frac{c_2}{\lambda T}} \sigma' \left(\frac{c_2}{T}\right)^4 \tag{12}$$

FIG. 2.




Black body equivalent wave-lengths.

From this is immediately derived the relation

$$\frac{d \log \frac{L}{R}}{d\left(\frac{c_2}{T}\right)} = -\frac{1}{\lambda} + \frac{4}{\left(\frac{c_2}{T}\right)} \tag{13}$$

If now we substitute the complete expression for $\lambda_e$ from (10) we get

$$\frac{d \log \frac{L}{R}}{d\left(\frac{c_2}{T}\right)} = -\frac{1}{a + b\left(\frac{c_2}{T}\right) + c\left(\frac{c_2}{T}\right)^2} + \frac{4}{\left(\frac{c_2}{T}\right)} \tag{14}$$

Integrating this we get

$$\log \frac{L}{R} = \frac{1}{\sqrt{b^2 - 4ac}} \log \left( \frac{\frac{c_2}{T} + \frac{b + \sqrt{b^2 - 4ac}}{2c}}{\frac{c_2}{T} + \frac{b - \sqrt{b^2 - 4ac}}{2c}} \right)^{\frac{1}{\sqrt{b^2 - 4ac}}} \tag{15}$$

$$+ 4 \log \left(\frac{C_2}{T}\right) + A$$

Solving for numerical values this becomes

$$\log \frac{L}{R} = 71.005 \log \left( \frac{\frac{c_2}{T} - 137.16}{\frac{c_2}{T} + 53.378} \right) + 4 \log \frac{c_2}{T} - 19.6100 \tag{16}$$

This expression gives results of about one per cent. accuracy, and is considerably quicker than (2) to work with. Its derivation presupposes the true values known from the direct procedure.

NOTES TO APPENDIX.

[1] *Physical Review*, Feb., 1916, p. 161.

[2] Holst and Visser, K. Akad, Amsterdam, 1918.

[3] In the region of the gold point the calculated luminous efficiency changes almost exactly 1 per cent. for each unit in the fourth place of the assumed value of $c_2$. The present uncertainty in the value of $c_2$ is four or five units in this place (14300 to 14350).

This rapid variation of calculated luminous efficiency with $c_2$ suggests that a highly sensitive method of determining this constant lies in the experimental determination of $\frac{L}{R}$ for the black body at the well established gold point. L could be established photometrically by comparison with a light source of the same color as the black body at this temperature, but of sufficient intensity to furnish measurable radiation through a luminous efficiency curve filter of accurately known transmission. Such a source is at hand in the "4 watt" carbon lamp in conjunction with a 90 per cent. concentration "Fabry" yellow solution.

[4] JOURNAL FRANKLIN INSTITUTE, July, 1918, p. 122.

[5] *Bull. Bureau Standards*, 270, Mar., 1916.

**Salving Trench Hosepipe.** (*Journal of Industrial and Engineering Chemistry,* vol. xi, No. 7, p. 690, July 1, 1919.)—An interesting side line of war salvage is being carried on at Hayes, Middlesex, England, where some hundreds of miles of trench hosepipe are being disintegrated and the various products recovered for sale. This type of hose contains a large amount of iron wire and canvas impregnated with a small proportion of rubber. A special machine has been designed for treating the hose, and the stripped wire is stated to be worth about $60 a ton at present prices. The rubber is being reclaimed and the canvas ultimately finds an application as cellulose. The work is being done on a part of the premises of a detinning works, where considerable quantities of scrap tin are now being treated by the electrolytic process with satisfactory results. Metal containing as much as 99.8 per cent. of tin is being obtained from the scrap.

**Zirconium Steels.** J. GARCON. (*Bulletin de la Société d'Encouragement pour l'Industrie Nationale,* vol. 131, No. 1, p. 148, January–February, 1919.)—Zirconium is not found in nature in the metallic state. It occurs in Norway, Ceylon and Brazil, and nearly everywhere in the form of orthosilicate. Zircon or hyacinth contains two-thirds oxide of zirconium or zirconia and a third of the silicate with some impurities. Its density is very high, reaching 4.7. Another richer mineral is badelyte, of which quite copious deposits are found in Brazil and also in Ceylon. This is a natural zirconia whose content of $ZrO_2$ varies from 69 to 94 per cent. Several methods are followed to obtain more or less pure oxide. Zirconia is employed, in view of its high temperature of fusion, in the manufacture of crucibles and for the linings of metallurgical furnaces. Zirconium enters also in the composition of Nernst-lamp filaments, in the leads of the Bleriot-lamp, and as a component of a special glass which may be substituted for quartz-glass.

An important application of zirconium is found in the manufacture of alloy steels. Tests at the Ford laboratory on armor-piercing-bullet-shields have shown that nickel-zirconium steel plates 10 mm. in thickness have a resistance to penetration equivalent to nickel-chrome steel 16 mm. thick and nickel-molybdum steel 13 mm. thick. The zirconium is added in the form of a 30 per cent. ferro-alloy. This alloy is produced by reducing the mineral in the electric furnace with aluminum. It is essential that the alloy contain not more than 5 per cent. of aluminum, otherwise the presence of the aluminum diminishes the strength of the steel.

# DEVELOPMENT OF AN AIRPLANE SHOCK RECORDER.*

BY

A. F. ZAHM, Ph.D.

Bureau of Construction and Repair, Navy Department.

To meet the current needs of the airplane designing staff of the U. S. Navy, an airplane accelerometer was developed for measuring the sudden loads and shocks encountered in flying, and landing. An elaborate instrument of precision was not called for, but rather a device whose records could be obtained easily and read directly. For the scale drawings and early tests of the design here described the writer is indebted to his assistant, Mr. L. Crook, who first calibrated the accelerometer, then used it on a flying boat to measure landing shocks.

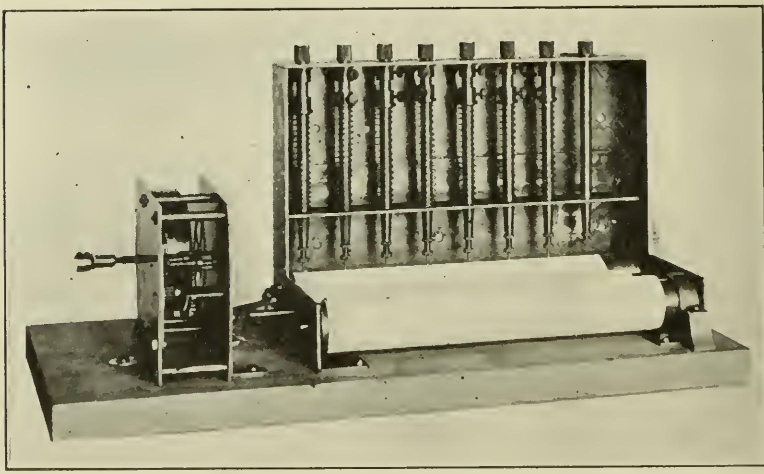
Fig. 1 pictures the instrument in course of development. It consists of many vertical styluses, or pointed rods, supported individually by springs and recording on a single chronograph drum over which passes a continuous sheet of sensitized paper. For measuring upward accelerations the rods, which are all of the same mass, are pressed upward against stops by springs of graded intensity, while their pointed lower ends, or needles, are held within a few thousandths of an inch of the chronograph drum. When acceleration occurs a certain number of styluses begin to record instantly, as the intensity of the force overcomes in succession stronger and stronger springs.

When preparing the instrument for any proposed measurement one sets the springs so as to meet any probable accelerations that will have to be recorded. By means of the sliding sleeves shown in the photograph the force of the springs can be adjusted so as to equal any multiple of the weight of a rod. To this end one applies in succession to each stylus, by contact with a weighing scales, forces which are multiples or fractions of the whole fixed weight of the rod plus half the weight of the spring, while the springs are adjusted so as barely to support the rod against the stop. A single rod of brass weighs about 1¾ ounces, being $^9/_{32}$ inch diameter by 5 inches long.

* Communicated by the Author.

To prevent the needle from scratching or puncturing the paper it is cushioned against a spiral spring inside the holder, or vertical rod, within which it can otherwise slide freely. The needle at its middle is provided with a shoulder abutting against the upper end of the small holding and adjusting screw. This screw can, by rotating, raise or lower the setting of the needle, and is securely fixed in place by the jam nut shown at the bottom of the rod. The needle is of brass or German silver, and makes a clear, fine mark on the chemically treated paper when the pressure is three per cent., or more, of the weight of the holder. One

Fig. 1.



per cent. of the weight would be sufficient pressure with styluses fifty per cent. longer and thicker, for a test has shown that .05 ounce pressure of the needle causes a clear trace.

In the position and adjustment shown, the present instrument records only upward accelerations, but by inversion can, without further adjustment, record downward accelerations, provided account be taken of the reversed direction of gravity. Thus, if when upright, the stylus exerts on the stop a pressure $nw$, inverted it exerts $(n+2)\ w$; and hence records accelerations $ng$, $(n+2)g$, $w$ being its weight. Without inversion the instrument also records negative accelerations if the styluses be pressed downward against their stops. Also in its upright position the

instrument records both positive and negative accelerations when the springs are set so that some styluses are pressed upward and others downward.

The special stylus shown on the right of the photograph is provided at its upper and lower ends with thin cantilever springs which prevent it from rubbing against the guide plates of the containing box, and at the same time hold the rod upward against its stop in the manner described for the spiral springs. An instrument with such cantilever, or anti-friction, springs could be used to measure horizontal as well as vertical accelerations.

In the form here shown the instrument is provided with six feet of paper driven by an alarm clock at the rate of two inches per second for such accelerations as are found in aeroplane experiments. This rapidity is essential in order to separate and clearly disclose landing shocks and structure vibrations; for it is usually the short hammer-blow shocks of a few hundredths of a second duration which most stress the under parts of an airplane in alighting on land or water.

In action the instrument appears to be fairly instantaneous and free from the oscillations found in a spring accelerometer whose recorder has a considerable displacement. Thus each needle records without interruption a definite continuous acceleration beyond a certain intensity, but instantly ceases recording when the acceleration falls below this amount. It can also simultaneously record long and short accelerations. For example, engine tremors superposed upon an air swell cause a needle to make a dotted trace; the length of the trace representing the duration of the swell beyond a certain intensity, and the distance between dots representing the period of the engine tremor. In fact, a known engine speed serves to standardize that of the paper, and a known paper speed that of the engine. The aggregate tracings of all the needles form a shaded diagram whose contour is a wavy line like that of a spring accelerometer.

An example of typical records taken on a seaplane is presented in Fig. 2 of this report. The farther stylus, which has its restraining spring adjusted to record upward accelerations of twice gravity, has made a few instantaneous traces separated by long blanks; the one set for two-tenths of gravity has made long traces with short blanks. Both records are dotted, showing engine tremors. Feeble accelerations were expected, otherwise a more

suitable setting of the springs would have been made. They should have been graded to tenths in the region of two gravities.

Fig. 3 gives an acceleration record of an approximately simple harmonic motion, somewhat damped, made with the instrument

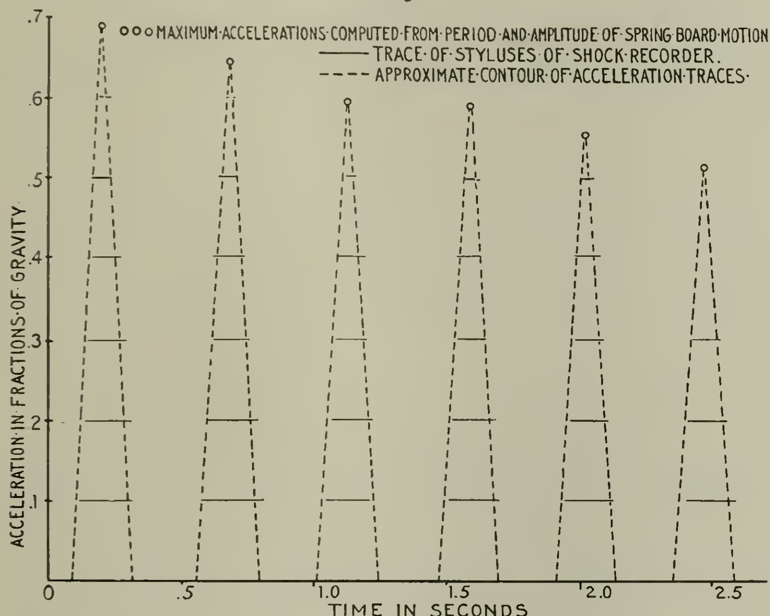
FIG. 2.


Landing accelerations on pontoon of Curtis JN—4E.

screwed to the end of a vertically vibrating spring-board clamped in a firm vise on a not very firm table, and with its styluses set only for positive accelerations. Plotted on the same diagram, as a line of small circles, are the simultaneous maximum accelerations of a needle inserted in the end of the spring-board and play-

ing on a sheet of smoked paper moving steadily past it. The line of circles is a "damped" harmonic with a perceptible "overtone," and matches the damped acceleration trace taken simultaneously, all recorders being equally distant from the face of the vise. The actual tracing of the spring-board tip is given in Fig. 4, and the method of computing from this the maximum accelerations, which are indicated by the circles in Fig. 3, is developed in the following paragraph.

FIG. 3.




Calibration diagram for shock recorder.

Without rigorous precision the general equation to the vertical motion of the spring-board tracing point may be written

$$\ddot{s} + a\dot{s}^2 + b\dot{s} + cs = o$$

in which $s$ is the displacement, at any time $t$, from the point of rest under gravity, and $a\dot{s}^2$, $b\dot{s}$, are retardations due to the air resistance and internal friction of the vibrating system. The maximum acceleration for any one vibration occurs when $\dot{s} = o$, and may be written from the equation

$$\ddot{s} + cs = o\cdot$$

It is

$$\ddot{s}_1 = -cs_1$$

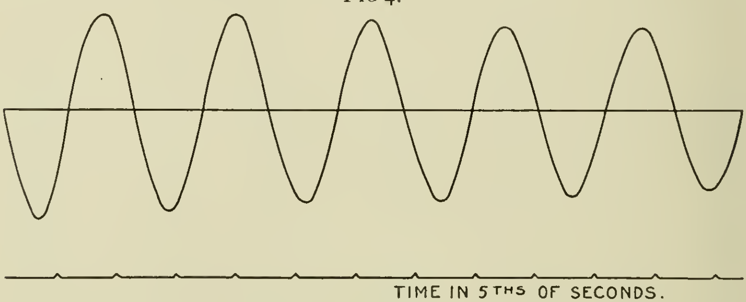
in which $s_1$ is the momentary amplitude. Since the damping is small, $\ddot{s}_1$ can also, without material error, be written in the more familiar form

$$\ddot{s}_1 = -4\pi^2 n^2 s,$$

when $n$ is the frequency. Now, since $\ddot{s}_1$ is approximately recorded by the acceleration styluses, and $\ddot{s}_1$, $n$, are found in the record of the vibration stylus, the one record can be checked with the other. This method was used in computing from the trace of the spring-board's motion, the accelerations indicated by circles in Fig. 3.

The acceleration records are fairly trustworthy as far as they go, but lack continuity, like the markings on a yardstick. To

FIG 4.




Trace of tip of vibrating spring board used in calibrating accelerometer.

disclose accurately the maximum acceleration in any shock the adjustment of the springs must be close-graded. Thus, if a maximum acceleration of twice gravity be recorded by styluses graded to tenths of gravity, the greatest possible error is presumably one-tenth of gravity, or five per cent. of the quantity recorded, while the probable error is two and one-half per cent. Still closer estimates can be made by sketching in the contour of the traces. The free play of the styluses between their stops must, of course, be kept small.

Closer agreement between the two sets of superposed values in Fig. 3 would ensue if the clock ran uniformly; if the paper were uniformly thick, instead of being spliced; if the needle points were set 0.004 inch from the paper, instead of 0.012 inch; and if the styluses were given less play between their stops. These adjustments would be made in refining the instrument. But, even so, the records would not everywhere accurately disclose the acceleration, unless made with numerous styluses in close-graded

adjustment. At one point, such as the third crest in Fig. 3, the record might be a mere dot, and hence indicate the acceleration truly; at another it might be a dash, leaving the true crest to be extrapolated. Numerous and close-graded styluses can, of course, be provided without much increase of cost or weight, if found desirable for special investigations.

For the immediate measurements in view it was thought unnecessary minutely to calibrate the shock recorder to a close-grade scale by experiment. Continuous recording instruments are in the market, such as the R A F photographic accelerometer, or in development, such as the Sperry mechanically recording accelerometer, and these may be had in time. The present instrument has served a passing need, and may prove useful for disclosing hammer-blow shocks too sudden to be faithfully recorded by accelerometers of another type.

For a comprehensive field laboratory study of the accelerations throughout an airplane it may be well to measure simultaneously the shocks in the undercarriage, the body and the wings. This can be done either by placing individual recorders in those parts, and synchronizing them, or by placing shock receivers there and recording on a central chronograph. The present instrument, or a simpler one consisting of plane bar springs, could be used as a contact maker in various parts of an airplane to operate recording magnets at a central drum. Such an apparatus can easily be arranged, and may be expected to record with about the promptness of a ballistic or an astronomical chronograph.

For instantly indicating to the pilot the comparative stressing of his machine a number of simple bar-spring contact makers of graded strength can be coupled to a row of tiny electric lamps on the instrument board. These would brighten successively, and indicate by their various colors, positions, or markings, the degree of stress put upon his craft. A tentative instrument of this kind has been tried incidentally to the present study. Such cantilever styluses, or contact makers, have the simplicity and compactness of a row of piano keys, but are not preferred to the endwise-moving styluses because they are more affected by angular accelerations about their centres of gravity, or points thereabout, than are the rods used in the present instrument. Obviously the contact points could be used with a smaller gap than have the needles recording on paper.

Without its base the present instrument, whose case measures 9 inches by 6 inches by 1.5 inches, weighs eight pounds, being made almost wholly of brass. By using aluminum, where practicable, the whole weight can be reduced to about two pounds. In this style the clock would form part of the case, and the whole could be screwed to the instrument board of an airplane.

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**Lignum-Vitæ, the Vital Wood.** S. J. Record. (*Scientific American Supplement,* vol. lxxxviii, No. 2270, p. 4, July 5, 1919.)—The propeller shaft of every battleship, every destroyer, every transport, in fact, every large steamship, revolves in a wooden bearing at the stern end. Of all the thousands of woods in the world, true lignum-vitæ, a native of the West Indies and certain other parts of tropical America, is the only one that has been found equal to this exacting service. The peculiar properties which so well fit lignum-vitæ for the purpose are due to the arrangement of the fibres and the resin-content of the sap cells. The fibres never run straight up and down the log, but weave back and forth in a serpentine manner that cross and criss-cross like the corded fabric of an automobile tire. The result is a material of extreme tenacity and toughness. When the sap cells cease to function, their every nook and cranny become filled with a resin which is about a third heavier than water. The result is a material which weighs about 80 pounds per cubic foot.

Stern bearings provide the most important use for lignum-vitæ but by no means the only one. Formerly it was in great demand for bowling balls, but now only one ball in ten is made of wood. A large quantity of low-grade logs, known as "cutting-up" wood, is consumed in the manufacture of rollers for furniture casters. Small round sticks make excellent mallets and fill a large demand, especially in England. Another important use is for sheaves of pulleys, and they have been known to last in constant use for seventy years. Another nautical application is for "dead-eyes," a small flattish block with a grooved rim to fit in the bight of a rope or encircled by an iron band, pierced with three holes to receive a lanyard, and used to extend the shrouds and stays. Among the miscellaneous uses may be mentioned stencil and chisel blocks, watchmakers' blocks, mortars and pestles, dowels, golf-club heads, wooden cogs, water wheels and block guides for band saws. In building the Panama Canal, the true lignum-vitae made the most serviceable railroad ties that could be obtained. Between 150 and 200 tons of genuine lignum-vitae are used every year in New York for fuel in grate fires. The very dense nature of the wood, together with the heavy resin content, produces a fuel with intense glowing heat and good lasting qualities. This provides one outlet for defective and crooked logs which are found in every shipment.

# PITCH POCKETS AND THEIR RELATION TO THE INSPECTION OF AIRPLANE PARTS.*

BY

J. R. WATKINS.

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Member of the Institute.

In the inspection of important wood parts for airplanes it is essential to know as accurately as possible the effect of any defect on strength. In the early days of airplane manufacture the builder could go to almost any length in securing wood entirely free from knots, imperfections of grain, pitch pockets, or any blemish or defect; in other words, absolute perfection could be insisted upon. When airplanes began to be manufactured on a large scale for war purposes and we began to look forward to a commercial development of the airplane it became impossible to insist on this absolute perfection. Consequently, accurate knowledge of the effect of all sorts of defects is becoming increasingly essential.

Among the defects found in the coniferous species used for airplanes, such as spruce and Douglas fir, a common one is pitch pockets. This article is a brief résumé of theories advanced to account for the presence of pitch pockets and the results of tests to determine the effect of pitch pockets on the strength of airplane wing beams. The tests were made at the Forest Products Laboratory of the United States Forest Service, in coöperation with the Air Service of the Army and the Bureau of Construction and Repair of the Navy.

### ORIGIN AND OCCURRENCE OF RESIN POCKETS.

Resin pockets are hollow recesses in the wood of conifers, which are more or less completely filled with resin.

A theory advanced about 75 years ago is that they are caused by the dissolving of wood parenchyma clusters in such a manner that wood tissues are transformed into resin.

Another theory[1] contradicts the first with the following statements: "*First,* the pitch pockets in the very newest annual

* Communicated by the Director of the Forest Products Laboratory.

[1] H. Mayr in "Das Harz der Nadelhölzer, etc.," pp. 36–40.

ring are lined with parenchyma just the same as those in wood over a hundred years old; there are no pitch pockets whose parenchymal lining is entirely dissolved away. *Second,* the pitch pockets are formed at a time and in a surrounding structure in which all processes are engaged in the direct opposite of dissolution; that is, in cell formation and reproduction; namely, in the cambium and during the cambial activity. The pitch pockets are filled with resin from the very first moment of their origin, even before the isolation parenchyma is fully formed. *Third,* fir (*Abies*) and arbor vitæ have abnormal parenchyma, like the spruce, but in neither of the first named species does one ever find a pitch pocket, since pitch pockets stand in a causal relation with resin ducts, which latter, as is well known, are absent in fir (*Abies*) and arbor vitæ.

"There remains, therefore, for the origin of pitch pockets, only the one explanation, that at the time of the cambial activity, resin is squeezed from the horizontal canals into cambial layers, which having been split thereby, are entirely separated for a certain extent of their surface by the outpouring of resin. This resin, gushing out into the soft, thin walled and as yet uncompleted layers, kills the neighboring cells, which then collapse. There then begins on the part of the more distant parenchymal cells, an inner overgrowth by means of the formation of proud-wood parenchyma, which isolates the resin which has poured out and in this way renders it harmless. The resin is squeezed into the cambial layers with such force that at this point a considerable expansion of the very thick bark results.

"It is difficult to determine what causes the pathological exudation of resin from the horizontal canals into the growing cambial layer. It is well known that, on account of the turgidity of the sapwood layers, the resin in the resin ducts is under very high pressure. The only way in which resin is made use of in the case of the spruces and pines is by pressure exerted upon the resin by the juicy sapwood. This is the only force which is able to overcome the resistance of the exceptionally fine capillaries (resin ducts). Wherever the tension due to the changing turgidity of the structure changes most rapidly, one finds the most pitch pockets.

"Because of this fact pitch pockets are most frequently found

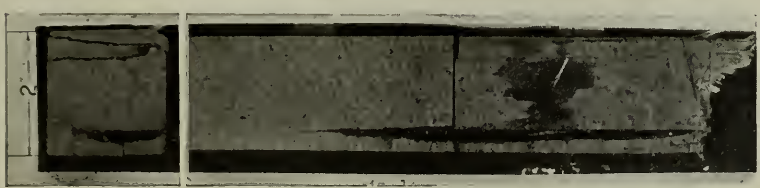
in the vicinity of branches from the main trunk. On account of these branches the ascending water current, which is deflected from the main course at an angle, is dammed up. Those trees which stand alone, and are therefore subjected to all extremes of temperature and humidity, are noticeably richer in pitch pockets than trees which have grown up surrounded by the forest."

Another theory is that the tree is wounded by means of some external force. The resin then flows to the wound, where it assists in protecting the surface against drying out until it can be healed by an overgrowth of proudwood.

### TESTS OF THE EFFECT OF PITCH POCKETS ON THE STRENGTH OF AIRPLANE WING BEAMS.

One investigator made a considerable number of tests of the effect of pitch pockets on small test specimens. He considered

FIG. 1.



Length 8 inches, width 1½ inches, depth ¼ inch. Showing pitch pockets and resin flecks in a piece of white pine.

that pitch pockets were evidence of a diseased condition of the wood. He also recommended that inspectors reject wood with very large pockets, and in the case of wood with pockets that are smaller but exceed 1 by ⅛ inch in dimensions special attention be directed to the grain, and all resin-pocketed wood showing slight general waviness or slight general obliquity of grain be rejected. He states that pitch pockets of 1 by ⅛ inch in dimension are not in themselves a cause of weakness and for this and other reasons the position of the visible pockets of this size on a finished airplane part is not of paramount importance. These tests were made in England on " silver spruce," presumably Sitka spruce.

The theory that pitch pockets are merely evidence of a diseased

condition seems untenable. In the many thousands of tests of various coniferous species made at the Forest Products Laboratory there has been no evidence that the presence of pitch pockets is indicative of a disease which weakens the wood.

During the early part of the war the rejection of wing beams and other important parts because of the presence of pitch pockets was quite large.

There are about 20 inspections of each beam and strut from the time it enters the mill until it goes into the plane and each inspection eliminates a fair percentage of the material. Following is a table of data compiled during one month by an inspector in a plant making DH-4 wing beams:

*Number and Percentages of DH-4 Wing Beams Rejected for Various Causes at Final Inspection.*

| Cause for Rejection. | Spiral Grain | Diagonal Grain | Dip | Knot | Pitch Pocket | Warp | Check | Damage | Wind Break | Glue Failure | Dote |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number rejected.... | 305 | 16 | 97 | 79 | 138 | 65 | 218 | 59 | 59 | 17 | 7 |
| Per cent. of total number rejected.... | 28.8 | 1.5 | 9.2 | 7.6 | 13.0 | 6.2 | 20.0 | 5.6 | 5.6 | 1.7 | 0.8 |
| Per cent. of total number inspected... | 4.4 | 0.2 | 1.4 | 1.1 | 2.0 | 0.9 | 3.1 | 0.8 | 0.8 | 0.2 | 0.1 |

Total Beams Inspected = 7016
Total Beams Rejected = 1060
Per cent. Rejected = 15.1

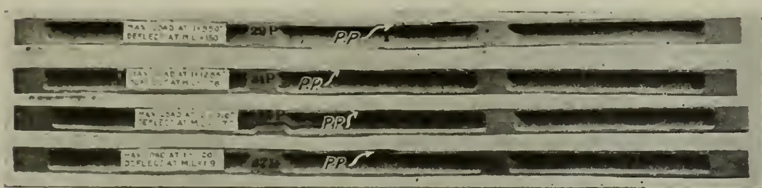
This inspection was of finished beams and the table does not indicate the percentage rejected before they had reached this stage.

At the suggestion and with the coöperation of Captain O. P. M. Goss of the Spruce Production Division, a series of tests to determine the effect of pitch pockets of various sizes located in different parts of Douglas fir wing beams was undertaken at the Forest Products Laboratory of the United States Forest Service, Madison, Wisconsin. Sixty pairs of Douglas fir beam blanks 2 by 4 inches by 7 feet were selected by Captain Goss at the mills. It was the intention in selecting these that one beam of each pair should be entirely free from pitch pockets and that the other should have pitch pockets in certain parts of the beam. Blanks giving

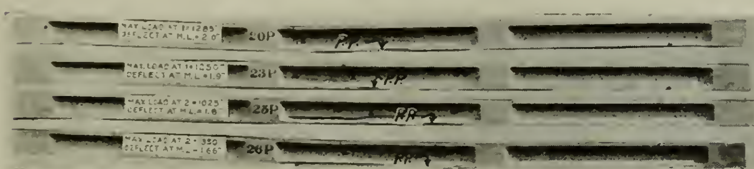
promise of filling these qualifications were selected and shipped to the laboratory. The two beams of each pair were taken from the same height in the tree and at the same distance from the pith, that is, from the same annual rings of growth.

On arrival at the laboratory this material was carefully kiln dried to about 10 per cent. moisture. The blanks were then routed to the I-beam form shown in Fig. 2 for test in bending over a span of 6 feet with loads at the third points of the span.

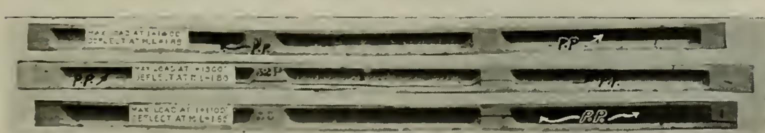
FIG. 2.



TYPICAL FAILURES OF BEAMS IN GROUP 1.



TYPICAL FAILURES OF BEAMS IN GROUP 2.



TYPICAL FAILURES OF BEAMS IN GROUP 3.

Pitch pockets and their influence on the mechanical properties of Douglas fir airplane wing beams. Showing typical failures of tested beams with pitch pockets in various parts.

These beams were 2¾ inches high by 1⅝ inches wide with ⅜-inch webs and flanges. A length of 3 inches was left unrouted at each support and each load point. Pitch pockets in some of the blanks were eliminated in the routing.

Beams were divided into groups 1, 2, and 3.

Group 1 included beams having pitch pockets in the compression flange and between load points. Group 2 included beams

having pitch pockets in the tension flange. Group 3 included beams having pitch pockets in the web and between support and load point. Each beam containing pitch pockets had a mate free from pitch pockets selected as previously described and tested in exactly the same manner.

Fig. 2 shows typical failures of beams of each group. The numerals "1" and "2" indicate the order in which failures occurred.

*Group 1.*—The first failure of all the beams in this group was by compression, or buckling at the pitch pocket. This shows conclusively that the pitch pocket had a weakening effect and was the cause of failure.

The following table gives the results of tests on individual beams of this group. The strength properties of each beam are given as a percentage of the same strength property of the beam matching it. The matched beam was free from pitch pockets or other defects affecting its strength.

Table I.

| Beam No. | Dimension of Pitch Pocket in inches | | | Modulus of Rupture | Modulus of Elasticity | Work to Maximum Load |
|---|---|---|---|---|---|---|
| | *L* | *W* | *D* | | | |
| | | | | *Per cent.* | *Per cent.* | *Per cent.* |
| 31 P | 2 | 1/16 | 3/4 | 99 | 85 | 93 |
| 22 P | 3 | 1/8 | .... | 93 | 106.5 | 87 |
| 33 P | 3 | 1/16 | .... | 98 | 101.0 | 100 |
| 37 P | 3 | 1/8 | 1 1/4 | 95 | 98.5 | 94 |
| 41 P | 3 | 1/16 | .... | 93 | 97.5 | 91 |
| 17 P | 5 | 1/8 | 1 1/8 | 77 | 99.5 | 55 |
| 35 P | 5 | 1/8 | .... | 88 | 88 | 86 |
| 29 P | 6 | 1/8 | 1 1/4 | 76 | 81 | 67 |

*L* = length of pitch pocket.
*W* = width of pitch pocket as seen on face of beam.
*D* = depth of pitch pocket, *i. e.*, distance it extends into beam.

All beams in this series had the annual growth rings horizontal in the beam, consequently, *W* is the radial and *D* the tangential (to the annual rings) dimension of the pitch pocket.

Beams from which the pitch pockets were eliminated in routing were also tested and compared to other clear beams matched to them in the same way as clear beams were matched to beams

with pitch pockets. There were 80 clear beams matched in pairs in this manner. Data from these tests are of assistance in interpreting the results given in Table I. These data show that "matched" pieces differ from each other even when both are free from defects.

| | Modulus of Rupture | Modulus of Elasticity | Work to Maximum Load |
|---|---|---|---|
| Average ratio of strength property of a clear beam to that of another clear beam matched to it | .990 | .988 | .996 |
| Probable deviation of individual ratio from average | .044 | .046 | .111 |

The figures on "probable deviation" indicate that with material selected and matched, as in the present instance, a piece which is clear of defects will in one case out of four be expected to be no more than 94.6 per cent. as strong in modulus of rupture as its mate (also free from defects). The corresponding figures for the other properties are modulus of elasticity 94.2 per cent., work to maximum load 88.5 per cent.

From this it is seen that two of the four pieces with 3-inch pitch pockets fall below their mates by an amount which would be expected to be found somewhat less frequently than one time out of four in the case of pieces free from defects. The piece with a 2-inch pitch pocket falls well within this limit for modulus of rupture and work to maximum load. It will be noted that the damage from 5-inch and 6-inch pitch pockets is quite serious in beams of this size.

*Group 2—Pitch Pockets in Tension Flange and Between Load Points.*—The pitch pockets in this group were not greater in length than four inches and in one case only did the line of failure pass through the pitch pocket.

*Group 3—Pitch Pockets in Web Between Support and Load Point.*—Beams in this group were tested to ascertain the effect of pitch pockets on the strength in horizontal shear.

The fact that in beam No. 55 (see Fig. 2) the horizontal shear failure passes through the pitch pocket and the further fact that this beam failed at a lower load than did its mate may be taken as an indication that a pitch pocket of this length (4 inches) constitutes a weakening in horizontal shear.

The conclusions reached from these tests are that:

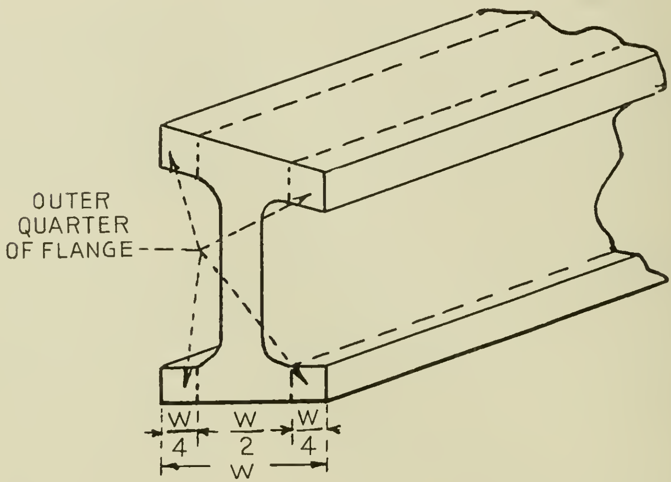
1. The effect of a pitch pocket is dependent on its size and location.

2. The effect of small pitch pockets on strength properties is probably much smaller than has been supposed.

While these tests were on Douglas fir only, there is no reason to suppose that the results are inapplicable to other species.

The tests are not sufficiently numerous to fix definite limits to the size of pitch pockets which may be permitted in different parts of various airplane members. In fact, it may easily be seen that

FIG. 3.




a very large number of tests would be required to cover the possible combinations of size, character and location of such pockets.

The following suggested general specifications for wing beams of I-section (solid or built-up) are based not only on the tests described above but on many years' observation by members of the Forest Products Laboratory of the effect of pitch pockets and various other defects on strength properties and on failures under test.

(*a*) At points where the computed stress multiplied by the loading factor is equal to the maximum allowable stress the beams must be entirely free from pitch pockets.

(*b*) At points where the computed stress multiplied by the loading factor or so-called "factor of safety" does not exceed

90 per cent. of the maximum allowable stress pitch pockets 1½ inches in length and not to exceed ⅛ inch in width or depth may be allowed in any part of the section, except the outer quarters of the flange—provided they do not cause a slope of grain steeper than 1 in 25 in the outer quarters of the flange. No pitch pockets to be allowed in outer quarters of flange.

(*c*) At points where the computed stress, multiplied by the loading factor, does not exceed 70 per cent. of the maximum allowable stress, pitch pockets 2 inches in length and not to exceed ¼ inch in width or depth may occur any place in the section, except in the outer quarters of the flange—provided they do not cause a slope of grain steeper than 1 in 20 in the outer quarter of the flange. No pitch pockets to be allowed in outer quarters of flange.

(*d*) At points where the computed stress, multiplied by the loading factor does not exceed 50 per cent. of the maximum allowable stress, pitch pockets, 1½ inches in length and ¼ inch in width or depth may occur in the outer quarters of the flange and pitch pockets 3 inches in length and ¼ inch in width or depth may occur in any other portion of the section—provided they do not cause a slope of grain steeper than 1 in 15 in the outer quarters of the flange.

(*e*) Pitch pockets in the web may not be closer together than 20 inches; if in the same annual ring they may not be closer together than 40 inches. In other portions of the section these distances may be 10 and 20 inches, respectively.

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Asphalt in the United States. (*U. S. Geological Survey, Press Bulletin,* July, 1919.)—Asphalt is widely known and has long been extensively used in road construction, but in recent years many producers of asphalt and allied substances have successfully marketed their products for other uses.

Asphalt is most largely used in this country in paving city streets and country roads, and, though its utilization in road building in 1918 was restricted chiefly to the maintenance of existing pavements and to new construction at cantonments, shipyards, and elsewhere in war work, a larger quantity of paving asphalt, binder, filler, road oil, and flux was made from petroleum and crude native asphalt and sold last year than had been sold in any one year preceding the war.

The uses of asphaltic materials, including both native asphalt

and asphalt made from petroleum, as well as gilsonite, grahamite, and elaterite, in buildings and other structures are manifold. As they are elastic, antiseptic, acid-resistant, and moisture proof, these materials are being widely employed for use in flooring and roofing, in waterproof coating, and in electric insulation, as well as in the manufacture of varnish, paint, and putty. Although these materials have been marketed for relatively few years they are in general demand among contractors and engineers and their use is rapidly increasing.

Gilsonite, the purest known hydrocarbon, has found great favor in the rubber industry. As pure rubber is sensitive to heat and cold it can not be used advantageously for making products that are exposed to extreme temperatures, but when it is mixed with gilsonite and the mixture is vulcanized the rubber undergoes changes in composition that enable it to resist variations in temperature as well as oxidation. The product of this mixture, which is called mineral rubber, is well adapted to outdoor use, and the demand for it is increasing.

Ozokerite, a native paraffin, is utilized in the manufacture of leather polish, sealing wax, electrotypers' wax, candles, electric insulation, carbon paper, and ink. Prior to the war all the ozokerite used in this country was imported, chiefly from Galicia, but when that source of supply was cut off a search was made for deposits in the United States, and this hydrocarbon first entered the market from domestic deposits in 1916. Most of the output in 1918 was used as an acid-proof coating for electrotypers' plates.

**American Chemical Society.** (*A. C. S. News Service*, July 14, 1919.)—The fifty-eighth meeting of the American Chemical Society will be held in the city of Philadelphia from September 2nd to 6th inclusive. The first general meeting will be held on Wednesday morning, September 3rd. One of the features will be the first session of the newly organized dye section. There will be a joint session of this section with the Division of Industrial Chemists and Industrial Engineers to consider a proposal to revise the patent laws. It has been suggested that the charging of a nominal annual renewal fee would compel many patentees to exploit their patents rather than to permit them to remain undeveloped for many years. Special arrangements have been made to give to all delegates to the convention access to the various chemical plants in and around Philadelphia. An opportunity to view the large munition works will also be given the visitors.

# RECENT PROGRESS IN THE MANUFACTURE OF GLASSES FOR PROTECTING THE EYE FROM INJURIOUS RADIATIONS.*

BY

W. W. COBLENTZ, Ph.D.

Associate Physicist, Bureau of Standards.

THE old saying that it is an ill wind that blows no one good, is well illustrated in the manufacture of optical glass.

One of the chief requirements in the manufacture of optical instruments is a colorless glass. Iron is the most common substance which causes discoloration in, and hence diminishes, the transmission of optical glass. On the other hand, iron impurities in glass have a marked absorption in the infra-red, the maximum being at about $1\mu$. This property may, therefore, be utilized in the manufacture of glasses for protecting the eye from infra-red rays.

Although it has not been definitely proven that infra-red rays are injurious to the eye, there seems to be a feeling that protection from these rays should be provided. Fortunately this can be done easily and cheaply. And now the most pampered can be provided with glasses which not only give protection from rays which are known to be injurious, but also supply the most exacting demands as to color, etc.

It is of interest to consider the transmissive properties of various glasses which, used separately or in combination, protect the eye from injurious radiations—particularly from ultra-violet rays.

The ideal glass would be one which absorbs all the ultra-violet and infra-red, and transmits only the visible rays, by an amount sufficient to prevent irritation and injury to the eye.

Four years ago the question of providing glasses for protecting the eye from injurious radiations was practically new and untouched. At that time the feeling was expressed [1] that: " It appears as though in the near future glasses fulfilling every

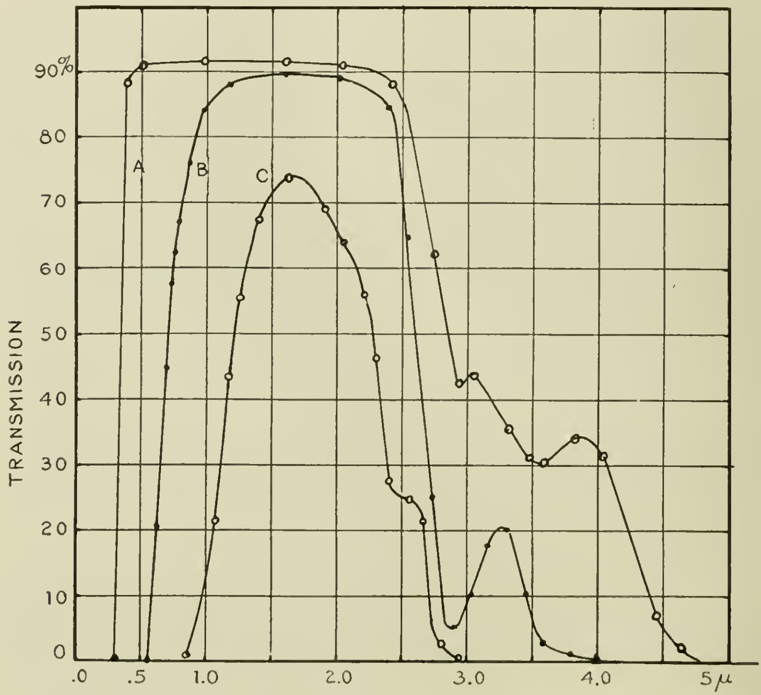
* Communicated by the Author.

[1] JOUR. FRANKLIN INSTITUTE, May, 1913.

requirement will be obtainable, and it speaks well for American enterprise to be willing to spend a few dollars in attempting to produce devices for safeguarding the health and contentment of the public."

In the meantime, this prediction has become a reality. The subject of eye protection has become national in importance, and manufacturers of eye protective glasses are meeting the most stringent requirements.

Fig. 1.




The variety of ways in which various manufacturers of eye-protective glasses fulfill these requirements, will be noticed in connection with the transmissive properties of various glasses, which will now be discussed. In most cases these glasses were about 2 mm. in thickness. More detailed data may be obtained by consulting the original paper.[2]

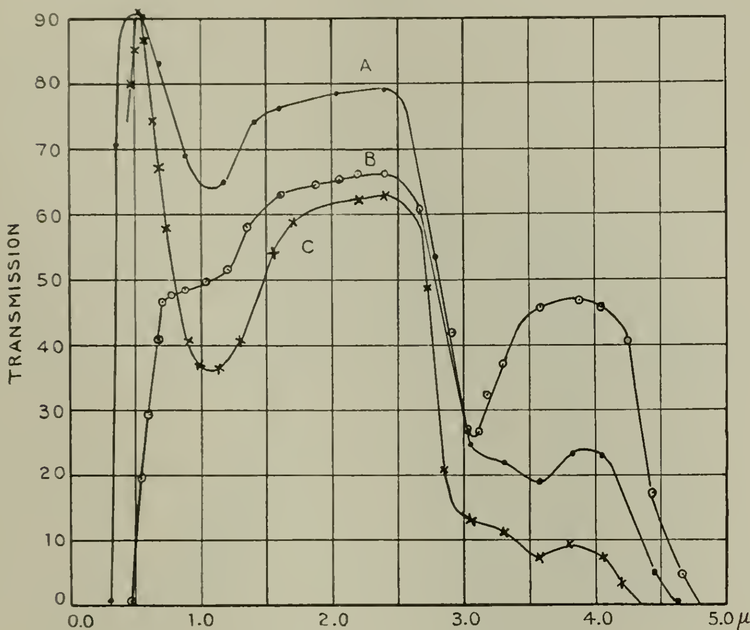
*Colorless Glass.*—It is of interest to note the characteristics

[2] *Bull. Bur. Standards*, 14, p. 663, 1918.

of optically colorless glass. Curve *A*, Fig. 1, gives the transmission of a sample of white crown glass which transmits ultraviolet to about 0.3$\mu$ and infra-red to about 4.8$\mu$. The shallow absorption bands at 2.9$\mu$ and 3.6$\mu$ are characteristic of glasses.

The presence of iron impurities produces a marked change in the transmission of a glass with an absorption band at about 1.1$\mu$. This is illustrated in curves *A* and *C* of Fig. 2, which

FIG. 2.




gives the transmission of window glass. Viewed edgewise, such glass appears tinged green.

*Red Glass.*—Curve *B*, Fig. 1, shows that red glass absorbs the ultra-violet and most of the visible rays. But it affords practically no more protection from infra-red rays than does clear glass.

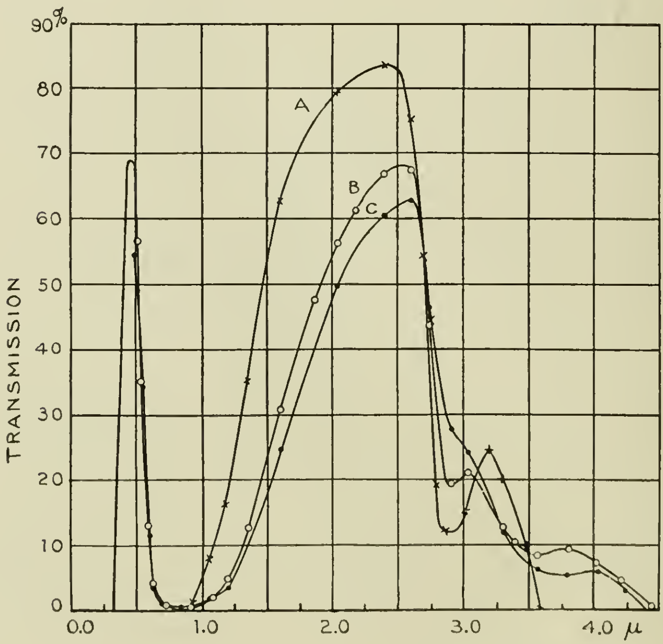
*Amber Glass.*—As illustrated in Curve *B*, Fig. 2, amber glass absorbs the ultra-violet and some of the visible spectrum. Iron impurities produce an absorption band at 1.1$\mu$. Aqueous solutions of iron alum have an absorption band at about 1$\mu$.

*Green Glass.*—Curves *A*, *B* and *C*, Fig. 3, show that green

glass is opaque to the ultra-violet and has a wide absorption band in the region of $1\mu$. In combination with other glasses, it affords suitable protection from injurious rays.

*Blue Glass.*—Curve *A,* Fig. 4, gives the transmission of a sample of cobalt blue glass. In spite of the fact that blue glasses transmit ultra-violet, they are used in some high temperature work. Combined with a deep amber, red or green glass, it affords protection from injurious rays. For example, Curve *C*, Fig. 5, gives

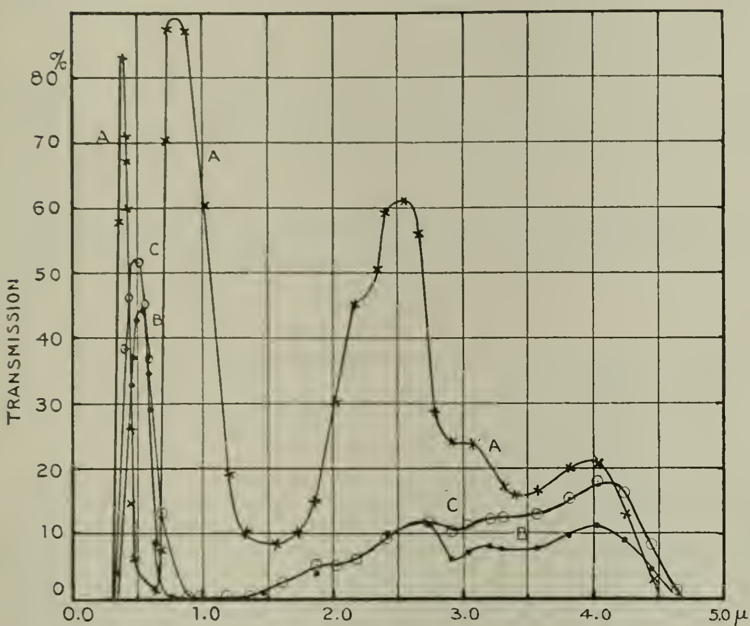
Fig. 3.




the transmission of a combination of several red and blue glasses used in arc welding. Curve *D,* Fig. 5, gives the transmission of a combination of a flashed red, a green and a blue glass used in oxy-acetylene welding. These two combinations were found to reduce the intensity of the visible rays by a suitable amount, and they afford proper protection from the infra-red and especially the ultra-violet. (In these two curves, *C, D,* Fig. 5, the transmissions are double the values indicated on the scale.)

*Sage Green and Blue Green.*—Two excellent glasses for

FIG. 4.


%
80
70
60
50
40
30
20
10
0
TRANSMISSION
0.0
1.0
2.0
3.0
4.0
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A
A
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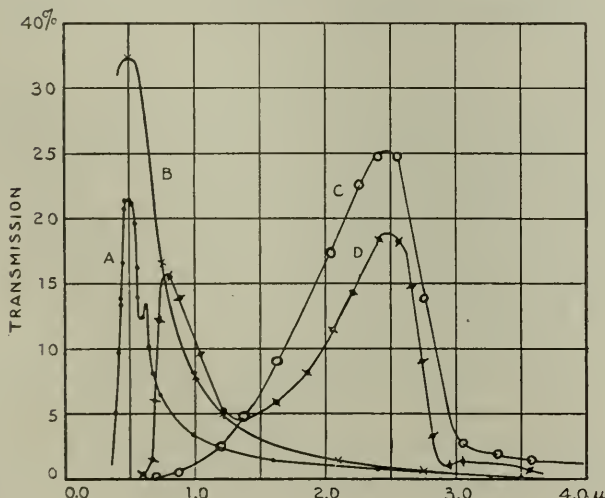
B
C
C
C

FIG. 5.


40%
30
25
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15
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TRANSMISSION
0.0
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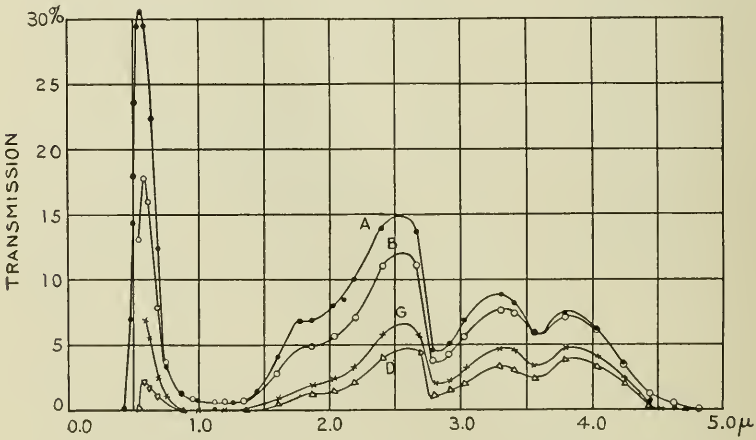
3.0
4.0 μ
A
B
C
D

absorbing the ultra-violet and infra-red are Crookes' ferrous sage green (American Optical Co., Curve *B*, Fig. 4), and Corning *C*, 124 *J.A.*, Curve *C*, Fig. 4.

*Gold Leaf.*—A thin film of gold on glass (obtained from *A.O.C.*; see Curves *A* and *B*, Fig. 5) eliminates the infra-red and ultra-violet, and by selecting the proper density provides also protection from visual rays.

*Black Glass.*—Ordinary "smoke" glasses are good for outdoor wear, but they do not give sufficient protection when working near sources of intense ultra-violet radiation.

FIG. 6.




Judging from the small number of "black" glasses submitted for test, in comparison with other glasses used in oxy-acetylene welding and cutting, it would appear that the so-called deep "black" glasses are not used extensively.

*Noviweld.*—This is a commercial eye-protective glass (Corning Gl. Works) which effectively absorbs the ultra-violet and infra-red rays. The transmissive properties of various shades are shown in Fig. 6.

*Dyes.*—Attempts have been made to use dyed celluloid films instead of colored glass for protection against harmful radiations. In this manner it seems feasible to absorb the ultra-violet and visible rays. But the writer knows of no dye which has marked absorption throughout the infra-red. As shown in Curve *C*, Fig. 1, a sheet of celluloid which is dyed so as to be

opaque to the visible and ultra-violet, is quite transparent in the infra-red.

The published data of others [3] shows that dyes (*e.g.*, green and violet dyes) which absorb the yellow and red become quite transparent in the infra-red. Hence, unless a dye is found which absorbs the infra-red, the outlook for substituting dyed films for colored glasses, for absorbing the infra-red, is not very encouraging.

The foregoing is a brief description of the characteristics of glasses readily obtainable, which singly or in combination afford protection from injurious radiations.

WASHINGTON, D. C., April 15, 1919.

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[3] *Pfund. Zeitschr. Wiss. Photog.*, **12**, p. 341, 1913; Johnson and Spence, *Phys. Rev.* (2). **5**, p. 349, 1915.

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**Precious Stones in the United States.** (*U. S. Geological Survey, Press Bulletin*, July, 1919.)—The value of the precious stones annually produced in the United States from the beginning of this century to 1914 has been about one-third of a million dollars. In 1914 and in every year since, the annual value of the output has dropped considerably, and in 1918 it dropped to $106,523, the lowest reported since the United States Geological Survey began to collect statistics of gem production, in 1883, with the single exception of 1896, when it was $97,850.

The report on the production of precious stones in 1918, just published by the Survey, ascribes the decrease in the value of the precious stones produced to the military enlistment of many gem miners, the general scarcity of labor, and the poor market.

The output consisted chiefly of the sapphire variety of corundum, which is nearly all used as mechanical bearings in watches and other instruments that require practically nonwearing frictionless bearings. Other less valuable and softer minerals used for this purpose are garnet and some forms of hard, compact silica, known as agate and chalcedony. The annual value of the output of the four gem minerals, corundum, quartz, tourmaline, and turquoise, amounts to over four-fifths of the total value of all the precious stones produced in the United States.

Montana, Nevada, California, Colorado, Maine, and Arizona are the chief gem-producing States, but from 20 to 30 States annually report some production.

Several relatively large diamonds were found in Arkansas in 1918, notably a canary-colored octahedron weighing nearly 18 carats and a number of smaller stones weighing several carats each.

The value of all the diamonds produced in the United States, however, in no year exceeds a few thousand dollars.

The report also records the finding of two large diamonds in South Africa, weighing about three ounces each. It is estimated that about half the diamonds in the world are owned in the United States and that their value is over a billion dollars. With the elimination of competition from German Southwest Africa 95 per cent. of the world's production of diamonds will be under the control of the De Beers Consolidated Mines Co. and its selling agents.

The report gives a short list of the industrial uses of precious stones of gem quality and full descriptions of the Iceland spar variety of calcite and of optical fluorite, states the special uses and necessary qualifications of the material, and includes lists of buyers.

The report on the production of precious stones in 1917 contains a full list of gem names, each followed by the name of the mineral species to which the gem belongs. A second list gives names of the mineral species, each followed by all the names of the corresponding gem.

**Central-Station Heating in Detroit.** J. H. WALKER. (*The American Society of Mechanical Engineers,* Spring Meeting, June, 1919.)—The general problem of the utilization of the heat ordinarily discharged to the condensing water in a central electric generating station is discussed. The impossibility of its complete utilization for the purpose of heating buildings and the difficulties in the way of even its partial utilization are pointed out, with particular reference to conditions existing in Detroit, Michigan.

The development of the central heating system of the Detroit Edison Company is traced, showing how the use of exhaust steam for heating was abandoned in favor of live steam. The reasons why it is more commercially expedient under the existing local condition to supply live steam to the heating system and to generate all electric current in the condensing stations are also fully brought out.

The paper also describes some interesting features of the central heating system in Detroit, such as the boiler plants, distributing system, underground construction of pipes and tunnels, consumers' installations and meters. Special mention is also made of distribution losses, condensation return lines, and the method of transmitting steam through feeders at high velocities and with large pressure drops.

The paper concludes with a discussion of the advantages of central heating service and of the obstacles to its wider use. It also points out the possibility of operating individual plants in combination with the central plant.

## NOTES FROM THE U. S. BUREAU OF STANDARDS.*

### SOME OPTICAL AND PHOTOELECTRICAL PROPERTIES OF MOLYBDENITE.[1]

By W. W. Coblentz and H. Kahler.

[ABSTRACT.]

THIS paper gives data on the transmissivity and the reflectivity of molybdenite; also data upon its change in electrical conductivity, when exposed to thermal radiations of wave-lengths extending from the ultra-violet into the extreme infra-red.

The effect of temperature, humidity, intensity of the exciting light, etc., upon the photoelectrical sensitivity of molybdenite was investigated.

It was found that:

(1) Samples of molybdenite, obtained from various localities, differ greatly in sensitivity.

(2) There are maxima of sensitivity in the region of 0.73$\mu$, .85$\mu$, 1.02$\mu$, and 1.8$\mu$.

(3) There is no simple law governing the variation in the photoelectric response with variation in intensity of the radiation stimulus.

(4) The increase in photoelectric current with increase in intensity of the incident radiation is greatest for infra-red rays. It is greatest for low intensities of the exciting light and it is greatest on the long wave-length side of the maximum.

(5) The photoelectric sensitivity increases with decrease in temperature. At 70° C. the bands at 1.02$\mu$ and 1.8$\mu$ have practically disappeared. On the other hand, at liquid air temperatures, the greatest change in electrical conductivity is produced by radiations of wave-lengths between 0.8$\mu$ and 0.9$\mu$.

Unlike selenium, molybdenite appears unique in being photoelectrically sensitive to infra-red rays, extending to about 3$\mu$.

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* Communicated by the Director.

[1] Scientific Paper No. 338.

## A STANDARDIZED METHOD FOR THE DETERMINATION OF SOLIDIFICATION POINTS, ESPECIALLY OF NAPHTHALENE AND PARAFFIN.[2]

By R. M. Wilhelm and J. L. Finkelstein.

[ABSTRACT.]

THIS paper, after a brief treatment of the definitions of melting and freezing points both of pure substances and of mixtures, describes a method of making solidification point determinations of naphthalene. This method was recommended at a conference of Bureau of Standards and U. S. Customs officials and is based on the well-known cooling curve or constant temperature method. The method is shown to be applicable to the determination of the freezing points of paraffin and other substances.

## THE STANDARDIZATION OF THE SULPHUR BOILING POINT.[3]

By E. F. Mueller and H. A. Burgess.

[ABSTRACT.]

THIS paper describes experiments made to complete the data which are required for the standardization of the sulphur boiling point as a thermometric fixed point. The precision attainable in calibration of resistance thermometers at the sulphur boiling point is so much higher than the accuracy of the gas thermometer determinations of the temperature that it was considered desirable to standardize the temperature corresponding to normal atmosphere pressure by definition at 444.°60, and the data from which this figure was deduced are given.

Experiments were made to determine the effects of type of radiation shield, the type of boiling apparatus and purity of sulphur, upon the temperature assumed by a resistance thermometer in the sulphur vapor. The conclusions reached were that if a radiation shield is to be effective, its inner surface should be a good radiator, that, within wide limits, the temperature is independent of the type of boiling apparatus used, and that sulphur of a high degree of purity, which is however readily obtainable, should be used.

The relation between the vapor pressure of sulphur and the

[2] Scientific Paper No. 340.

[3] Scientific Paper No. 339.

temperature, over the pressure range from 700 to 800 mm. was determined with a precision of 0.°01 or better. The result of this work is the equation:

$t = 444.°60 + 0.0910\ (p-760) - 0.000049\ (p-760)^2$ where $t$ is the temperature in Centigrade degrees, assumed by a properly shielded resistance thermometer in the standard form of sulphur boiling apparatus, and $p$ is the pressure, expressed in equivalent millimetres of mercury at 0° and under standard gravity ($g$ = 980.665). In an appendix are given the specifications for a proposed standardization of the sulphur boiling point.

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## METALLIC COATINGS FOR THE RUST-PROOFING OF IRON AND STEEL.[4]

[ABSTRACT.]

STEEL is protected against corrosion in a great variety of ways, including metallic and related coatings, paints, lacquers, varnishes, enamels, etc. The circular deals with the various types of metallic coatings, including those closely related in their nature and method of production (oxide and similar coatings). The methods of application and characteristics of the different metal coatings are discussed and it is shown that zinc, because of its electro-positive nature with respect to iron, is the metal to be relied upon when protection against corrosion is the prime consideration. Other considerations, *e.g.,* freedom from toxic effects, *e.g.,* for food containers, often lead to the choice of some metal other than zinc for a coating.

The structure and uniformity of distribution of the different classes of zinc coatings are discussed and their bearing upon the behavior in service is pointed out. Of the various methods which are used for the testing of coated materials, the " salt spray " test is by far the most satisfactory. The articles to be tested are exposed to a fine mist of a saturated salt solution and the length of time that they successfully withstand this severe exposure is a fair index of the service life that may be expected for the specimen. This test while not entirely satisfactory is the best which has yet been suggested.

A series of recommendations concerning the choice of protective metallic coatings for various types of works is given, together with a good working bibliography of the subject.

[4] Circular No. 80.

## LEAKAGE RESISTANCE OF ELECTRIC RAILWAY ROADBEDS AND ITS RELATION TO ELECTROLYSIS.[5]

By E. R. Shepard.

[ABSTRACT.]

Technologic Paper 127 of the Bureau of Standards, entitled "Leakage Resistance of Electric Railway Roadbeds and its Relation to Electrolysis," by E. R. Shepard, Electrical Engineer, gives the result of more than three years of electrical resistance measurements on different types of roadbeds. Electrolytic damage to underground piping systems is caused from the escape of current from the rails of electric lines and the resistance of the roadbed is an important factor in the amount of current which may escape.

Short sections of fourteen common types of roadbeds were constructed on the grounds of the Bureau of Standards and resistance measurements under varying weather conditions were carried on for a period of three years. Some measurements were also made on a number of city lines in and about Washington, both open track and several types of roadbed in paved streets being investigated. Through the coöperation of the United States Forest Products Laboratory at Madison, Wisconsin, measurements were also made on several sections of test track on the Chicago, Milwaukee and St. Paul Railway where railroad ties subjected to several different kinds of preservatives were employed. The results of these measurements are given in tabular and graphical form, and the following conclusions have been drawn:

1. Roadbeds constructed with solid concrete ballast and vitrified brick or other non-porous pavements have a low leakage resistance to earth which is affected only moderately by seasonal and weather changes. There is little difference between wood and steel ties in their effect on the resistance of roadbeds of this kind. Insulation is not of practical value in reducing leakage current from such roadbeds. The resistance of single roadbed of this type is from 0.2 to 0.5 ohm per 1000 feet, under ordinary conditions, but may be two or three times this when the ballast is frozen to a depth of 1 foot or more. For double roadbed of this type the resistance is approximately 70 per cent. of that for single roadbed, or the leakage from double track would be about 40 to 50 per cent. greater than from single track.

[5] Technical Paper No. 127.

2. Roadbeds constructed with a foundation of clean crushed stone under concrete paving base have a much higher resistance than roadbeds with a solid concrete ballast. In the case of the experimental roadbed the ratio was found to be about 3 to 1. Roadbeds with a full crushed stone ballast and a Tarvia finish have a very high leakage resistance which is of the order of 2 to 5 ohms per 1000 feet of single track. The leakage from a double roadbed of this type and other high-resistance types is from 80 to 100 per cent. greater.

3. The resistance of earth roadbed in which the ties are imbedded and therefore kept in moist condition is much lower than that of open construction roadbed, being from 1 to 1½ ohms per 1000 feet of single track under normal conditions and considerably more when the ground is frozen.

4. The resistance of roadbeds of open construction is subject to wide variation depending upon the condition of the ties and ballast. In very dry weather with good ballast the resistance will be 10 to 15 ohms or even more per 1000 feet of single track, but in wet weather it will drop to from 3 to 5 ohms. Cinder, gravel and particularly crushed stone, when used as a ballast in open-track construction, produce very high-resistance roadbeds. Earth has a tendency to keep the ties moist and therefore to increase the leakage. Open-construction track is often considered to be insulated from the earth, but this is not strictly true. Assuming a potential difference between the track and the earth of 5 volts and a leakage resistance of 10 ohms per 1000 feet the total leakage per mile would be 2.64 amp. This small leakage current would not ordinarily be harmful to underground structures in the vicinity of the track.

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## THE CONSTITUTION OF ALUMINUM AND ITS LIGHT ALLOYS WITH COPPER AND WITH ALUMINUM.[6]

By P. D. Merica, R. G. Waltenberg and J. R. Freeman, Jr.

[ABSTRACT.]

THE temperature-solubility curves of $CuAl_2$ and of $Mg_4$–$Al_3$ in aluminum were determined by the method of annealing and microscopic examination. Aluminum dissolves about 4.2 per cent.

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[6] Scientific Paper No. 337.

of copper as $CuAl_2$ at 525° C. and about 12.5 per cent. of magnesium as $Mg_4Al_3$ at 450° C.

The solubility of both compounds decreases with decreasing temperature. At 300° C. aluminum dissolves only 1 per cent. of copper as $CuAl_2$ and slightly less than 5.9 per cent. of magnesium as $Mg_4Al_3$.

The structural identification of the various constituents, $FeAl_3$, $CuAl_2$, $Mg_4Al_3$, found in alloys with magnesium and with copper is described, and a constituent is noted in all light aluminum alloys containing magnesium which is believed to be $Mg_2Si$.

The solubility of iron as $FeAl_3$ in aluminum is at all temperatures less than 0.15 per cent.

Small amounts of silicon up to from 0.12 to 0.20 per cent. are dissolved by aluminum at the eutectic temperature but are reprecipitated upon cooling corresponding to the diminished solubility for silicon of aluminum at lower temperatures.

Silicon in the usual commercial amounts is probably present as a compound of iron and silicon together with some aluminum. The composition of this compound is not known, but it separates out with aluminum and $FeAl_3$ at an invariant point at 610° C.

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**Large Engine and Small Power.** (*National Engineer*, vol. xxiii, No. 7, p. 325, July, 1919.)—The *Savannah*, the first ocean-going ship to use steam engine propulsion (1819), shows the difference between then and now of boiler pressures available, so much so that comparatively large engines were needed to develop what nowadays is considered small power. The engine of the *Savannah* was equipped with a cylinder 40 inches in diameter and 60-inch stroke, built by Stephen Vail, near Morristown, N. J. The boilers were constructed to carry a steam pressure of 20 inches, registered by a mercury gauge, and were built by Daniel Tod, of Elizabeth, N. J. The paddle wheels could be folded up like a fan and stored on deck when the sea was too rough for their use. Although both sail and steam power was used, the vessel made, on trial, ten miles with and against tide in one hour and fifty minutes. This equipment and performance of the *Savannah* and that of the *Mauretania* tells the story of achievement in marine performance.

# NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

## THE CONSTITUTION OF CAPSAICIN, THE PUNGENT PRINCIPLE OF CAPSICUM.[1]

By E. K. Nelson.

[ABSTRACT.]

MATERIAL for this research was prepared according to Micko's method for the preparation of capsaicin. The best yield obtained was 50 grams of capsaicin from 50 pounds of very hot cayenne pepper.

Methylation of capsaicin produces methyl capsaicin, and oxidation of this by means of alkaline potassium permanganate leads to veratric acid. Hydrolysis under pressure breaks capsaicin down into vanillyl amine (4-hydroxy-3-methoxy benzylamine) and a decylenic acid. That the decylenic acid in the molecule of capsaicin does not possess a normal chain is proven by the fact that on hydrogenation normal decylic acid (capric acid) is not formed, but an isomeric decylic acid melting lower than capric acid.

Capsaicin is therefore a condensation product of vanillyl amine and a decylenic acid. The synthesis of substances analogous to capsaicin is being undertaken, and will form the subject of a later communication. Some of these substances already prepared are extremely pungent.

## THE ZINC CONTENT OF SOME FOOD PRODUCTS.[2]

By Victor Birckner.

[ABSTRACT.]

EXAMINATION of the ash disclosed the presence of appreciable quantities of zinc in many food products. Bakers' yeast, wheat, oats, corn, barley, rye, and rice contained from 415 to 15 mg. of zinc per 1000 grams of fresh substances. In ordinary

* Communicated by the Chief of the Bureau.

[1] Published in *J. Am. Chem. Soc.*, **41**: 1115-21, July, 1919.

[2] Published in *J. Biol. Chem.*, **38**: 191–203, June, 1919.

market milk about 4.2 mg. of zinc was found per 1000 grams, and in human milk from 6 to 14 mg. per 1000 grams. Practically all the zinc in hens' eggs, amounting to about 0.005 per cent. of the yolk, occurred in the yolk.

From its constant occurrence in the yolk of eggs as well as in cows' and human milk, it is inferred that the element zinc exerts an important nutritive function, the nature of which is not at present understood.

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**Tumbler Switches.** (*Scientific American,* vol. cxxi, No. 3, p. 53, July 19, 1919.)—While the tumbler switch has long been the standard in most countries abroad, the United States has persistently stuck to the snap switch and the push-button switch. Of late, however, the advantages of the tumbler switch have come to be realized, and manufacturers have started in on the production of such switches. Some of the designs offered are typically English, while others are distinctly American in their simplicity of design. The new switches of the tumbler type are exceptionally attractive in appearance and convenient to use. A single button operates the mechanism, which is of the quick make-and-break variety. Incidentally, the tumbler switch is self-indicating, the position of the lever indicating whether the switch is "on" or "off" at a glance.

**Air Fans for Driving Electric Generators on Airplanes.** G. Francis Gray, John W. Reed and P. N. Elderkin. (*The American Society of Mechanical Engineers,* Spring Meeting, June, 1919.)—The authors describe the method employed by the Radio Development Section of the War Department in testing air fans used for driving the electric generators usually installed on airplanes for radio communication. They also discuss at some length the various types of air fans and present numerous photographs and curves clearly illustrating the construction of the fans and their operating characteristics.

The difficulty of the problem lay in designing a fan which would turn at constant speed in the air streams of widely varying speed set up by the airplane in flight. The various types of fans tested were: Fixed-blade fans of special blade shape; fixed-blade fans with wind brakes centrifugally regulated; fixed-blade fans using a friction clutch or a friction brake centrifugally regulated, and pivoted-blade fans in which the pitch is centrifugally regulated.

# NOTES FROM THE U. S. BUREAU OF MINES.*

## METHOD OF ADMINISTERING LEASES OF IRON ORE DEPOSITS BELONGING TO THE STATE OF MINNESOTA.[1]

**By J. R. Finlay.**

At the request of the State Auditor of Minnesota the Bureau of Mines undertook an investigation of the methods of administering State leases of iron ore deposits. As the material in the report submitted is of great general interest it has been published for the benefit of the mining industry in general. The State of Minnesota owns 40,400 acres of land known to be ore-bearing, containing 168,000,000 tons of iron ore of present commercial grade. These ores are mainly leased under agreements that expire at the average date of 1952, under a royalty of 25 cents per ton and an agreement that the lessee shall work the mines in a manner which is customary in skilful mining. Two points are therefore involved: whether the mines are actually being so worked, and on what ores shall the State demand royalties. The ores range in grade from 65 per cent. down to 30 per cent. iron, average ore shipments are 56 per cent. iron, and it is therefore practicable to mix higher grade ores with lower grades, providing the latter are above the limit of profit. The investigation shows that ores under 48 per cent. iron dry or 42 per cent natural are not profitable to work under present conditions. Concentrating ores which run only 30 per cent. iron up to 50 per cent. iron is only an apparent exception, since in this case it pays to add to the cost of production in order to reduce the cost of transportation. Whether the "paint rock," which averages about 50 per cent. iron, is an ore is a matter of dispute between State officials and lessees. The conclusion of the author is that under present conditions it cannot be considered as ore, and its removal in underground operations is not justified. In open cut operations it has to be removed anyway, and it can be kept segregated in case it may eventually prove of value. The

* Communicated by the Director.

[1] Technical paper 222.

taconite or "iron formation" averages about 35 per cent. iron. At the eastern end of the Mesabi range there is an area in which the taconite has been so magnetized that its concentration by magnetic processes is possible. At the present time the capital investment required to make this separation is too large compared to the margin of profit, but it is not at all impossible that at some future time the value of the product or the cost of construction of the plant may be so altered as to make this material commercial ore. The author is confident that enough ore is available in Minnesota to keep up shipments of the present grade for 30 years. There is not much ground for anxiety as to the conserving of these possible sources of future wealth. The ores are indestructible and the great bulk of the formations are not likely to be so mixed by mining operations as to become utterly inaccessible. In some instances ores leased by the State at a royalty of 25 cents per ton have been sub-leased at a higher royalty and it is not fair to the people of the State for the operator to refuse to mine ore that would meet the 25 cents royalty but will not meet the higher royalty. This can only be met by negotiations between the operators and lessees for modification of royalty conditions. The conclusion of the author is that the State lands, so far as the iron mines are concerned, have all been well and properly administered.

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## ELECTRODEPOSITION OF GOLD AND SILVER FROM CYANIDE SOLUTION.[2]

By S. B. Christy.

Electrolytic precipitation of gold and silver from cyanide solution would seem, on the face of it, not to offer any great difficulty since the electro-plating of gold and silver is a well-developed art. But as a matter of fact, a great many practical difficulties develop since the solutions resulting from the cyanide treatment of ores are a rather complex mixture of salts, and no really satisfactory substance has been found for the insoluble anode that must be used. The precipitation of these metals by the use of zinc shavings or dust is so relatively simple that their electro-deposition has never come into general use, although a patent for such a process was issued 20 years before the McArthur

[2] Bulletin 150.

and Forrest patent on the cyanide process of gold recovery appeared. Meanwhile a number of processes for this purpose have been patented. At intervals over a period of 20 years Professor Christy studied the problem and took out a patent for a process of his own in 1900. Like the other patented processes it never came into general use, but in the course of his investigations Professor Christy performed an enormous amount of experimental work, which is recorded in this monograph. This careful record of experiments covering all phases of the subject under investigation is of great value for reference for investigators in the field of electrolytic deposition of metals.

## ELECTRIC FURNACE LABORATORY EQUIPMENT AT SEATTLE STATION, U. S. BUREAU OF MINES.

By Charles D. Grier.

The power supply equipment of the electric furnace laboratory at the Seattle Station, which has recently been installed, consists of two 140 kva. transformers and two duplex induction voltage regulators for supplying low tension current, and a three-panel switchboard and bus bar system for its distribution. As different furnaces are built to fit the needs of the various problems presented, connections can be made between the bus bar system and the furnaces, and either single or two-phase power supplied at any voltage between 35 and 484 volts.

The transformers and regulators are connected on the primary side to a 2,500-volt line from the Municipal Power Plant. The secondary coil of each transformer is divided into four sections, each of which has a normal voltage of 78 volts. The voltage of each of the secondary coils of the regulators can be made anything from 43 volts "boosting" to 43 volts "bucking," according to the relative position of the coils. Each transformer secondary coil is connected in series with a secondary coil in one of the regulators and it may be considered that the combination of each transformer and its regulator is a transformer with four coils, each capable of delivering 450 amperes at any voltage between 35 and 121 volts.

On the switchboard are mounted high and low tension voltmetres, ammetres for both phases, a power factor metre indicat-

ing and recording wattmetres and a watthour metre. Various switches permit connecting the transformers both on a single phase or one on each of the two phases, on the primary side, and of connecting the secondary coils in multiple, series, or series-multiple. The motors which operate the voltage regulators are controlled by push-button switches on the board, so that control of the furnace voltage within wide limits is effected by merely pressing buttons on the switchboard, and changes through the extreme range involve only two very simple switch changes.

The capacity of the equipment is a maximum when the regulators are boosting the maximum. At such a time the rated capacity is 435 kva. At the lowest voltage the capacity is 126 kva. The apparatus is therefore capable of delivering as much power as is used by small commercial furnaces. This capacity, the wide voltage range and the simplicity of control, make the equipment a remarkable group of apparatus.

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## CARBON BLACK FROM NATURAL GAS.

**By G. St. J. Perrott and R. O. Neal.**

An investigation of the carbon black industry has been undertaken by the United States Bureau of Mines as a result of economic issues brought up during the war. Considerable field work has been done. Plants in Louisiana, Oklahoma, and West Virginia have been studied by Bureau engineers. The uses of carbon black have been carefully investigated with the idea of determining the properties of the product which users of carbon black demand, and with an attempt at designating in which of these uses carbon black is essential and in which a substitute material might be employed. Microscopic and chemical examination of a large number of blacks is being made and test methods studied with a view to finding the reason for the very different behavior exhibited by different blacks.

In the present process of manufacture, carbon black is produced by burning natural gas with an insufficient supply of air for complete combustion and collecting the liberated carbon on a metal surface. Manufacturers of carbon black believe that this process is the only one in practical operation which produces a carbon black suitable for the ink trade and rubber industry. Over

10,000,000 pounds annually are used in ink manufacturing; 20,000,000 pounds annually are used in making automobile tires.

A Bureau of Mines bulletin on the Manufacture, Properties and Uses of Carbon Black is in process of preparation.

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MINOR NOTES.

*Rare Metals.*—The investigation of the metallurgy of Wulfenite, made at the Golden Station of the Bureau, has been completed and a report upon it will shortly be issued. The work upon the production of zirconium from its ores is almost completed. A bibliography of vanadium is also in course of preparation.

*Fire Extinguisher Liquids.*—An investigation of the various types of commercial carbon tetrachloride fire extinguisher liquids, made at the Pittsburgh station of the Bureau, has demonstrated that when these liquids strike burning wood or red-hot iron the carbon tetrachloride is partly decomposed and small amounts of toxic gases are formed, so that such extinguishers must be used with caution in confined spaces.

*Army Gas Masks in Fires.*—Tests of the army type gas mask for use in the irritating and choking smokes produced in fires show that it offers complete protection against these, but allows carbon monoxide to pass through. The coöperation of the fire chiefs of the principal cities was secured in making the investigation. A report of this investigation will shortly be published. These masks have also been tested in railway tunnels, and the results show that they should be of considerable use to engine men when passing through tunnels.

*Carbon Determination.*—A laboratory method for the determination of graphitic carbon in the presence of amorphous carbon has been standardized at the Pittsburgh station of the Bureau, and is now being checked on a large number of natural graphites and amorphous carbon in the form of coal. The method gives promise of being suitable for the direct quantitative determination of graphitic carbon, which up to the present time has always been an uncertain indirect determination. A laboratory method for the determination of the various forms of sulphur in coal has been tried on a number of typical samples of Eastern coal with very satisfactory results.

*Corrosion of Rifle Barrels.*—An investigation of the after-

corrosion of rifle barrels is in progress at the Pittsburgh station, in coöperation with the Ordnance Bureau of the War Department. The investigation is not yet completed, but the indications from the work already done are that corrosion is due to solid products of combustion that can only be removed by alkali or organic solvents.

*Steam Boiler Tests.*—The boiler tests which have been made by the Bureau's engineers for the Emergency Fleet Corporation at Erie, Pa., with such excellent results to date, are to be continued. A series of tests has been started in which oil is used as the fuel, and when the series is completed, a powdered coal test will be made in coöperation with the Erie City Iron Works. A series of tests on the use of coke for house heating purposes is now in progress, comparative tests being made with anthracite. An investigation has been started to determine the cause of the incrustation of boiler tubes when using underfeed stokers.

*Phosphorous in Iron Ores.*—An investigation has been started by the Minneapolis station to determine whether it is feasible to leach out the phosphorous from medium and high phosphorous iron ores. In connection with this an attempt will be made to develop a standard method for the determination of phosphorus in iron ores that will be satisfactory to both buyers and sellers.

*Mining Conditions Abroad.*—George S. Rice, Chief Mining Engineer of the Bureau, has returned from an extended investigation of mining conditions in the Saar and Rhine Valley districts, France, Belgium and Great Britain, and reports that the shortage of fuel that prevailed during the war still continues and there is probability of a still more serious deficiency unless the United States increases its exports. This is due more to the general unrest of labor and the increase in the cost of production (which are 75 to 150 per cent. above those prevailing in 1913) than to the physical destruction of coal mines and their equipment. In Great Britain the working hours underground have been reduced from 8 hours to 7, effective July 16, and Sir Auckland Geddes has made the statement that this will result in a production for 1920 of 70,000,000 tons less than in 1913, and an increase in price to the consumer. Meanwhile notice has been given in the House of Commons that the price is to be raised $1.50 per ton on July 16. This curtailing in output and increase in price in England, coupled with a shortage of coal in western and central Europe, where the various countries need 50,000,000 tons per year over their normal

pre-war sources of supply, from countries other than Great Britain. France alone needs 20,000,000 tons per year. The best estimates are that Great Britain will be able to export somewhere between 7,000,000 and 25,000,000 tons in 1919 to all foreign countries. There will therefore be a deficit of somewhere around 40,000,000 tons of fuel, for which the United States is the only visible source of supply.

The mines destroyed by the Germans in the Nord-Pas de Calais coal fields produced 20,000,000 tons of coal per year. It will take two to five years to get these mines in working condition and ten years to completely restore the production rate. The taking over by France of Alsace and Lorraine and its occupation of the Saar Valley will yield a certain amount of coal to make up this deficiency, but as a large part of the output of these districts is used locally the amount that can be counted on from these sources is uncertain as yet, though it is reasonably certain that it will nowhere near make up for the shortage in the Nord-Pas de Calais district. The mines in Belgium were not injured, but there is a shortage of skilled miners, and general labor conditions are such that there is likely to be a deficiency of 40 per cent. of the output as compared with pre-war figures. Half of Spain's coal is normally imported from England, eight-tenths of Holland's coal is imported largely from Germany. Norway, Sweden and Denmark have all heavily drawn on Great Britain for coal. Germany's principal coal-producing district is Westphalia. The only handicap under which this district labors is the general unrest and the weakened condition of the working population through insufficient food. The Ruhr field will probably be called on to deliver a good deal of bituminous coal and coke to France in exchange for the iron ore needed to keep the Ruhr blast furnaces operating. The outlook for a demand for coal for export from the United States is correspondingly bright.

**Surplus Electric Power After the War.** J. W. BECKMAN. (*American Electro-Chemical Society, Transactions,* 34th General Meeting, 1918.)—It may be the case that we will have a surplus of developed electric power after the world has settled down to a normal stride, this power having been developed in this emergency for the supplying of munitions to us and our allies. It is, therefore, important to face this fact now and consider how it may be avoided or overcome.

It would be an economic waste of the very gravest magnitude if this energy available on the bus-bars should be permitted to be idle, a waste from two points of view: (1) from the point of invested capital in the plant and equipment, and (2) perhaps a still graver waste, from the point of merchandise that could be produced, thus creating values and giving occupation to labor skilled and otherwise helping to supply work to the millions of men who will return to us after the war is won.

It is very apparent that many of the industries which are now operating in connection with the war will have to let up some, and equally certain it is that the power which they thus release will not be absorbed readily by any other industry. This certainly will be the case if we do not as a nation and as individual groups coöperate to extend our foreign markets, *i.e.*, to tap new market possibilities.

Two industries, both of them basic and both of them making products essential to mankind, suggest themselves as being suitable life-savers to the electric developments after the war. One is the iron and steel industry and the second is the fertilizer industry. When I refer to the iron and steel industry, I do not refer either to the electric shaft furnaces in Sweden nor to the electric steel furnaces distributed all through the country.

I think the direct manufacture of steel from iron ore is not out of the realm of the possible, and is one of the important electro-metallurgical developments awaiting a successful solution.

We have already progressed some toward this goal. In the electric shaft furnace low-carbon pig iron is now produced, known as steel pig iron or pig steel. The next step will be the finished steel, suitable for the manufacture of the finished steel product in the shape of ingots and castings. It may be a long step metallurgically to take, but it is one that we should bend all our efforts upon to achieve. If we once accomplish it, we will find the iron industry gradually changing into an electrometallurgical one, consuming enormous amounts of power and stimulating incidentally other industries to activities of very great proportions.

The other industry which would help to consume power is the fertilizer industry. The ingredients necessary in a fertilizer which would be most available for improved manufacture would be nitrogen in some bound form, and phosphoric acid.

# THE FRANKLIN INSTITUTE.

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## CORRESPONDENCE.

BUREAU OF CONSTRUCTION AND REPAIR, NAVY DEPARTMENT.

*Mr. R. B. Owens,* WASHINGTON, D. C., July 2, 1919.
*Secretary, Franklin Institute,*
*Philadelphia, Pa.*

MY DEAR SIR:

During my absence in Europe, there was received at my office the certificate of my election to Honorary Membership in The Franklin Institute, dated April 16, 1919. It has recently come to my attention that this certificate was not acknowledged, and I feel much mortification at the apparent neglect.

I beg to assure you and the members of the Institute of my deep appreciation of the honor conferred upon me.

Very sincerely,
(Signed) D. W. TAYLOR,
*Rear Admiral,*
*Chief Constructor of the Navy.*

---

JOHN J. CARTY,
195 Broadway,
NEW YORK.

*Doctor R. B. Owens, Secretary,* July 15, 1919.
*The Franklin Institute, Philadelphia, Pa.*

DEAR DOCTOR OWENS:

I have just been discharged from the Army and am at work on affairs which have accumulated and which require my attention.

. I have had a most gratifying surprise in receiving the diploma showing that I have been elected to be an Honorary Member of The Franklin Institute. This coming upon the other honors and courtesies which I have received at the hands of your society places me under so many obligations that I can never sufficiently express my feelings of high appreciation of The Franklin Institute and of its distinguished officers and members.

I assure you that I shall endeavor always to show that I am sensible of this great honor which has been conferred upon me.

Very sincerely yours,

JJC-AM (Signed) JOHN J. CARTY.

## BOOK NOTICE.

THE REALITIES OF MODERN SCIENCE. An Introduction for the General Reader. By John Mills, Research Laboratories, Western Electric Co., Inc. 321 pages, contents, index, 44 illustrations, 12mo. New York, The Macmillan Company, 1919. Price, $2.50 net.

Several useful books for popularizing science have appeared of late years from American authors. Some of these have been condensed histories, others accounts of scientific procedures, principally chemical, expressed in non-technical language. They have been of much service in bringing to notice the value and the methods of modern science. The present work is more strictly scientific, but is well adapted to those who want information on some of the data of physics and chemistry, especially the border-land of these two sciences, physical chemistry, which has progressed at such a rapid rate in the last quarter-century.

The work begins with an exposition of the author's views as to the methods of the beginnings of knowledge, which, as might be expected, is the least satisfactory part of the book, as the information at hand on this point is very scanty, and in a book which deals so largely with exact scientific data, this presentation of the speculations—telescopic deductions from microscopic premises, as they have been termed—is a discord in the music. The author states among other things that monkeys probably use tools only in imitation of human beings, and that having no thumbs they cannot pick up articles. It is, however, stated on good authority that even in the wild state they throw sticks and stones at intruders, and they certainly have the ability to pick up even small objects. These questions are, however, of minor importance and do not in any way affect the merit of the work, which gives valuable information on some of the latest and most important phases of physical chemistry. Large space is devoted to the subjects of electrons, electrolytic dissociation and the various problems of molecular physics. The book will be a valuable contribution to the literature of the subject.

HENRY LEFFMANN.

## PUBLICATIONS RECEIVED.

*The Realities of Modern Science:* An Introduction for the General Reader, by John Mills. 327 pages, illustrations, 12mo. New York, The Macmillan Company, 1919. Price, $2.50.

*Induction Coils in Theory and Practice:* By Prof. F. E. Austin, E.E. 64 pages, illustrations, 8vo. Hanover, N. H. Author, 1919. Price, $1.

*Illinois Department of Registration and Education, Division of the State Water Survey:* Bulletin No. 15. Chemical and Biological Survey of the Waters of Illinois. Report for year ending December 31, 1917. 133 pages, map, 8vo. Urbana, State printers, no date.

*University of Missouri, School of Mines and Metallurgy:* Forty-eighth Annual Catalogue. 163 pages, 8vo. Rolla, University, 1919.

*United States Geological Survey:* Advance Statement of the Production of Copper in the United States in 1918, by B. S. Butler. 6 pages, 8vo. Washington, Government Printing Office, 1919.

*U. S. Department of Labor, Working Conditions Service:* How to Give Illustrated Lectures on Accident Prevention to Workmen. 13 pages, 8vo. Washington, Government Printing Office, 1919.

*U. S. Bureau of Mines:* Bulletin 151, Recovery of Gasoline from Natural Gas by Compression and Refrigeration, by W. P. Dykema. 123 pages, illustrations, plates, 8vo. Bulletin 165, Bibliography of Petroleum and Allied Substances in 1916, by E. H. Burroughs. 159 pages, 8vo. Bulletin 176, Recent Developments in the Absorption Process for Recovering Gasoline from Natural Gas, by W. P. Dykema. 90 pages, illustrations, plates, 8vo. Bulletin 179, Abstracts of Current Decisions on Mines and Mining, reported from September to December, 1918, by J. W. Thompson. 166 pages, 8vo. Monthly Statement of Coal-mine Fatalities in the United States, March and April, 1919, compiled by Albert H. Fay, 2 pamphlets, 8vo. Technical paper 222, Method of Administering Leases on Iron-ore Deposits Belonging to the State of Minnesota, by J. R. Finlay. 40 pages, illustrations, 8vo. Technical paper 223, Cost Keeping for Small Metal Mines, by J. C. Pickering. 46 pages, diagrams, 8vo. Technical paper 224, Metal Mine Accidents in the United States During the Calendar Year 1917, compiled by Albert H. Fay. 80 pages, 8vo. Washington, Government Printing Office, 1918–1919.

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**The Production of Liberty Motor Parts at the Ford Plant.** W. F. VERNER. (*The American Society of Mechanical Engineers*, Spring Meeting, June, 1919.)—The contract made with the United States Government called for 5000 motors and these were to be produced at the rate of 50 per day of eight hours. To do this, important developments in the methods of manufacture were brought about by the Production Department of the Ford Motor Company.

One of these was the method of producing cylinders from tubing. Six operations were necessary and the author describes them in detail. The methods employed to produce connecting-rod crankshaft bearings likewise resulted in a great saving of time. Twenty-one operations were found necessary for this work and a complete description of each is given. The method of installing bearings in the upper and lower halves of the Liberty motor crankcase, is also described.

# CURRENT TOPICS.

**The Alcohol Problem.**—This note is not to discuss the question of the proportion of alcohol constituting a beverage as "intoxicating" nor the sociologic phases, but to point out that the practice of civilized countries of imposing heavy taxes on ethyl hydroxide is one of the most serious interferences with industrial development. Standing next to water as a general solvent, and having solvent powers on a large number of important substances not soluble in water, alcohol now finds extended use in the arts. Although governments have endeavored to release industrial alcohol from the tax burden, yet the only method so far generally adopted—that of incorporating with it ingredients that render it unfit for internal use—is by no means satisfactory. Apart from the uses of alcohol as a solvent, its adaptability as a fuel both directly and in the internal combustion engine opens up a great opportunity. It is of lower energy, weight for weight, than gasoline, but the fire-risk is so much lower and the odor unobjectionable.

The United States Government should institute a comprehensive research with a view of discovering cheap methods of producing alcohol and of devising means by which it can be sold freely for use in everything but beverages. The problems are complicated but they are not unsolvable. One question always presents itself to the law-maker, namely, the loss of revenue that will follow the removal of the tax. The restrictions that are imposed on the manufacture and sale of alcohol are due to the wide-spread opinion that taxes should be raised largely on luxuries, and alcohol has always been regarded as of this type, but apart from the changed conditions that will follow nation-wide prohibition, it surely is possible that taxes can be levied so as to be incident on the luxury and not on useful applications. The subject is too extensive to be discussed fully here, but it is well worth careful consideration by those interested in the advancement of the industries. H. L.

**Ash Removal by Suction.** (*Scientific American*, vol. cxx, No. 25, p. 661, June 21, 1919.)—What is virtually a large-sized vacuum cleaner has been delivered to a concern in New York City that specializes in cleaning ash bins of public buildings and large residences, and while the apparatus is experimental because it is now being tested out, the designers feel sure that it will prove to be not only practical and efficient, but will meet with the approval of the general public by minimizing the discomforts and dirt now met with in ash removal by the usual means of dumping the filled galvanized iron containers into open cart bodies.

The equipment is mounted on a five-ton chassis and is a large box compartment, resembling the conventional van, the doors and gates of which can be closed tightly. On the chassis is mounted a blower that is driven by the engine, and this is so adapted that ashes are drawn into the compartment from the ash pit, no matter what the angle, through a telescoping metal tube. The truck is driven to the curb at the nearest point to the ash pit, and the tube is extended into it. The ashes must be shoveled to the lower end of the tube and the suction carries them into the compartment on the truck.

The labor is limited to shoveling into the ash pit, or at least handling so the ashes can be drawn out by the blower, and there is no dust blown about outside. The time of loading the truck is much more rapid than would be possible were the work done manually, and this is of material importance when the time of trucks is considered as representing a substantial value. The prevention of dust will be approved by all sanitary departments of municipalities. The work of the apparatus is so satisfactory that adoption will soon be general, both for municipalities and for contractors.

**Insect Helps Control Other Insects.** (*U. S. Department of Agriculture, Bulletin No.* 766.)—An European parasitic fly that may become of far-reaching importance in the control of the gipsy moth and brown-tail moth and certain other serious pests of similar character is being multiplied from importations of this new insect enemy. A report of the work with the parasite—known as *Compsilura concinnata*—has just been made by entomologists of the United States Department of Agriculture.

This report shows that this parasite has reduced the damage done by the gipsy moth and the brown-tail moth in the New England States, where they were so abundant and destructive that they ate the leaves off enormous areas of forest and shade trees every year. It has been found that *Compsilura* also aids in the control of other insect pests.

The white-marked tussock moth, a serious pest in the New England States a few years ago, has practically disappeared since *Compsilura* has become established. The cabbage worm, still a serious pest, has been lessened in some sections. Celery worms are not as common as formerly, and the fall webworm is scarcely noticed in the Northeastern States now.

The entomologists do not claim that this parasite is the sole cause of this reduction, but it has proved an important natural enemy to all of them. It is thought that *Compsilura* may become one of the most important economic parasites in this country.

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# Journal of The Franklin Institute

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## THEORY AND PRACTICAL ATTAINMENTS IN THE DESIGN AND USE OF RADIO DIRECTION FINDING APPARATUS USING CLOSED COIL ANTENNAS.*

BY

A. S. BLATTERMAN,

Captain, Signal Corps, U. S. Army.

### INTRODUCTION.

It is a common enough experience in radio stations to be able to hear signals on a sensitve receiving set when the antenna is disconnected entirely from the apparatus. In such cases the tuning coils of the receiver pick up energy directly and the signal produced depends upon the electromotive force induced in the coils by the alternating magnetic flux component of the passing wave which threads through the windings. Another familiar example of coil reception is afforded by the ordinary wavemetre. Such small coils as these are, of course, extremely poor receivers; but the fact that they do receive enough energy at all over distances of the order of a number of wave-lengths at once leads to speculation as to the possibility of using larger coils especially designed for the efficient reception of signals.

In considering this problem the average engineer would at once conclude that the coils should be given large area, many turns and low resistance. The questions that he would probably not be able to answer, however, would be—How large shall the

* Communicated by Maj.-Gen. George Owen Squier.

area be, and how many turns. As a matter of fact, his first conclusions would only be partly correct, for while it is, of course, desirable to keep the resistance down to the lowest possible value, it has been found that the size of the coil and the number of turns cannot be illimitably increased without seriously reducing the efficiency. Actually, there exists for every wave-length a certain set of optimum dimensions giving maximum response at the detector. These facts have not been generally recognized heretofore, and although closed coil or loop receivers have been in practical use for the reception of signals over long distances for several years, they have not, up to the present time, been built according to completely rational designs. The proper size of the loop, the number of turns, the size and kind of wire and the spacing of same has been largely a matter of good technical judgment.

In addition to the use of the coil or loop for ordinary receiving purposes to replace the antenna, one of its most important practical applications comes from its directional qualities. It requires but little thought to realize that a coil placed with its winding plane perpendicular to the direction of travel of passing electromagnetic waves will have induced in it no voltage at all, while if it is turned around through 90 degrees so as to be in line with the wave propagation it will be threaded by maximum flux and develop its maximum *e.m.f.* This at once presents the possibility of locating the direction of any transmitting station that may be heard, and it has been found possible by correct design to build apparatus capable of locating such directions with an error not exceeding plus or minus ½ degree. Actually, a great many factors affect the accuracy of the device as a direction finder and the best results can only be obtained by properly taking all of them into account. Theoretical analysis of the effects involved has led to the development of methods for greatly improving the accuracy of the loop for direction finding and also to the important invention of a method for determining, by means of a single isolated loop structure, not only the *line* of a distant transmitting station but also its *sense* or *absolute* direction.

It is the purpose of the present paper to summarize an investigation that has been carried out in the U. S. Signal Corps Radio Laboratories during the latter part of 1917 and 1918 of all of these factors that enter into the efficient design of direction find-

ing apparatus using the loop antenna. No loop receiver can ever be made to be as efficient a collector of radio energy as a well-designed elevated antenna system and recourse is usually had, therefore, to the use of very sensitive detecting apparatus involving vacuum tube detectors and vacuum tube amplifiers in order to get the desired strength of signal. There are other reasons, also, of a more involved nature which make it necessary to employ specially designed amplifying apparatus in connection with the loop direction finder, so that while the main points to be discussed in this paper are those dealing with the efficiency of the loop as a receiver, its proper design, and with its directional properties, a few paragraphs are also devoted to investigations that have been made on the subject of amplification for this particular class of work. The experimental data presented with reference to the design of the loop for high efficiency is reasonably complete and would appear to be sufficient to allow fairly exact mathematical formulation. This phase of the problem has not been developed, however, in the present report.

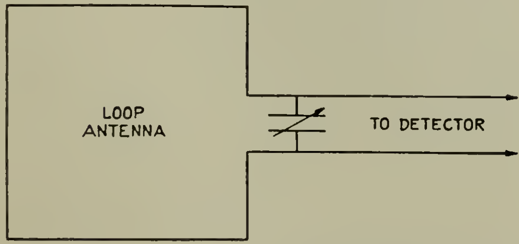
## PART I.

### DESIGN OF THE LOOP RECEIVER.

#### GENERAL THEORY.

THERE are several ways in which the loop receiver may be connected to the detecting apparatus, but the one most commonly used and the one that is considered in this paper is that

FIG. 1.




shown in Fig. 1, where it will be seen that a variable air condenser is connected directly across the loop terminals for tuning and the voltage developed across this condenser is impressed upon the detector.

The engineering problem presented is that of proportioning the loop so that this voltage will be as high as possible. The points involved, as will appear shortly, are:

1. Determination of best size of loop and number of turns for given wave-length,
2. Effect of spacing the turns of the winding,
3. Effect of size and kind of wire,
4. Effect of insulation and coloring matter in same,
5. Proper size of tuning condenser,
6. Effect of proximity of loop to walls of rooms,
7. Effect of the presence of dead or unused turns on coil;

and in order to come to practical conclusions of value to the engineer in building such coils it was necessary to study several other points, such as the effects of obtaining a given flux linkage or a given inductance through the use of large area and few turns or with smaller area and a large number of turns. Thus, in the following pages, sections are also devoted to the cases of:

1. Constant flux linkages with variable turns and area.
2. Constant inductance with variable turns and area.

This part of the investigation is then completed by working out from the data accumulated a design chart which enables all of the principal dimensions of a loop to be quickly determined when the working wave-length is given.

Let

$h$ = Instantaneous value of field intensity at the loop.
$H_o$ = Max. instantaneous value of $h$.
$\lambda$ = Wave-length.
$N$ = Number of turns on loop.
$A$ = Area of a turn.
$L$ = True self-inductance of loop.
$R$ = Total effective resistance of loop.
$C$ = Capacity of tuning condenser.

The instantaneous value of *e.m.f.* induced in the loop is

$$e = N \frac{d\phi}{dt} \cdot 10^{-8}$$

$$= NA \frac{dh}{dt} \cdot 10^{-8} \quad \ldots\ldots (1)[1]$$

If the field varies harmonically,

$$h = H_o \sin \omega t \quad \ldots\ldots (2)$$

[1] If the loop is of the flat pancake type the value of NA to use is the summation of the individual areas of all the turns, *i.e.*, $\sum_1^N A$

and (1) becomes

$$e = NAH_o\,\omega \cos \omega\, t \times 10^{-8}$$

Therefore, the instantaneous current in the loop and through the tuning capacity, $C$, is, at resonance,

$$i = \frac{E}{R} = \frac{NAH_o\,\omega \cos \omega t \times 10^{-8}}{R}$$

and the effective value of this current is

$$I_{eff} = \frac{NAH_o\,\omega \times 10^{-8}}{R\sqrt{2}}$$

The voltage across the tuning condenser due to this current is, as has been stated above, used to actuate the detector and its value will be a measure of receiving efficiency. This voltage is (approximately)[2]

$$\begin{aligned} E_c &= I_{eff}/\omega C \\ &= \frac{NAH_o \times 10^{-8}}{\sqrt{2}\,RC} \\ &= \frac{4\pi^2V^2H_o}{\sqrt{2}} \cdot \frac{NAL \times 10^{-8}}{\lambda^2 R} \\ &= K\left(\frac{NAL}{\lambda^2 R}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3) \end{aligned}$$

From this it appears that we have in general to deal with the problem of making the factor $NAL/\lambda 2_r$ as large as possible. This factor has been termed the "reception factor" in what follows.

At first sight, it would seem that a given loop would become increasingly more effective as the wave-length was shortened. In practice, however, such is not the case and audibility measurements have indicated that there is a certain best wave-length for a given loop above and below which the reception falls off.

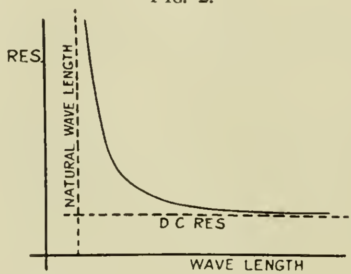
The reason for this can be directly traced to the fact that the loop resistance is not constant but changes with the wave-length. At very long wave-lengths the resistance approaches its *d.c.* value. As the wave-length is shortened, however, the resistance increases, slowly at first, up to a point 2 or 3 times the natural period of the coil when it rises almost asymtotically (see Fig. 2), and it is this inverse variation of effective resistance with wave-length

[2] This expression is not exact because part of the capacity is that of the loop itself which is distributed and does not all carry the total current I.

that produces the maximum value in the reception at a particular wave-length already mentioned. The reception factor curve drawn as function of wave-length has the form shown in Fig. 3.

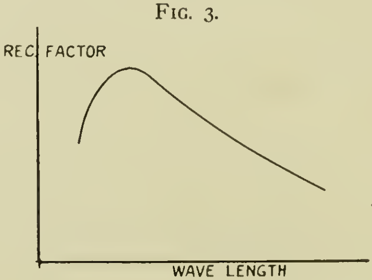
The variation of resistance just described is due to a combination of several effects, being chiefly caused by the capacity between

Fig. 2.




turns of the winding, but involving also the effects due to eddy current loss, skin effect, electromagnetic radiation, and losses in nearby imperfect dielectrics. It is very greatly affected by the number of turns, the size of the loop, and the spacing of the wires. It is also influenced, though to a lesser extent, by the actual *d.c.*

Fig. 3.




value of resistance, the diameter and shape of the wire and whether stranded or solid.

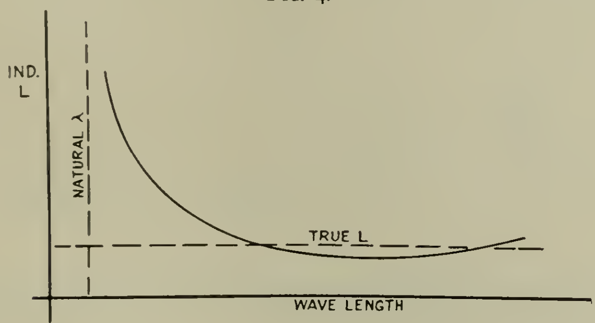
It is to be noted that the apparent inductance of the loop varies with the wave-length (Fig. 4) in a manner similar to the resistance but less abruptly. The increase in apparent inductance at short wave-lengths is due to the effective shunted capacity of the loop. The slight rise at long wave-lengths is due to the disappearance of skin effect.

For a given wave-length the equation (3) would indicate the

use of many turns, large self-induction and a large loop. These factors cannot be changed, however, without at the same time raising the natural wave-length of the loop and its effective resistance; and there actually comes a time when increasing the size of the loop and the number of turns is detrimental. There is, in fact, a certain best value of turns, area, spacing, etc., for any given wave-length. For short wave-lengths only a few turns can be used and the proper combination is quite critical, while for long waves where a large number of turns are employed, deviation from exactly best proportions is less serious.

No loop may be efficiently used at wave-lengths less than 1.5 to 2 times its fundamental.[3]

FIG. 4.




**METHOD OF MEASURING LOOP EFFICIENCY.**

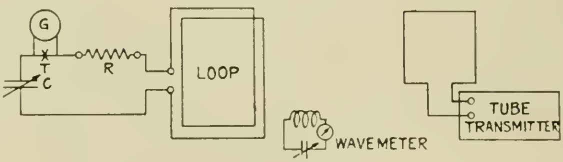
The method used in studying the various factors that enter into the design of loops was very simple. For each different set of conditions the effective resistance was measured at different wave-lengths, and from the physical dimensions of the loop and the data on its resistance thus obtained the reception factor $NAL/\lambda 2r$ was calculated. This procedure was particularly well adapted to manipulation in the laboratory, and was justified by the results of a number of special tests made over considerable distances in which the audibility of received signals was measured directly at different wave-lengths. A description of these tests

[3] The above discussion neglects entirely the reaction of the induced loop oscillation on the wave. The effect is very small, however, with this type of antenna.

is given later. They check the performance of the loop as calculated from measurements of its resistance.[4]

The "Resistance Variation Method" was used in determining loop resistance (see Fig. 5). The loop to be measured was inserted in a series circuit containing a variable air condenser known to be free from losses, and a low resistance thermoelement, *T,* and galvanometer, *G.* The galvanometer chosen was one which gave, accurately, deflections proportional to the square of the current in the thermoelement *throughout its entire range.* The thermoelements used were made up at the National Bureau of Standards and had resistances somewhat less than one ohm. The galvanometer was a single pivot Paul instrument, giving full scale deflection with about 80 milliampères. Various known resistances could be inserted at *R.* These resistances consisted

FIG. 5.




of fine manganin wires a centimeter or so in length enclosed in glass tubing and fixed to heavy copper wire terminals which dipped into small mercury cups.

The loop to be measured was coupled directly with and carefully turned to a vacuum tube generating circuit, the wave-length measured, and several resistances inserted successively at *R,* the galvanometer deflection being read for each resistance. The resistance of the loop was then calculated from the formula

[4] Attention should be called to the fact that the value of resistance in the expression for the reception factor is the total effective resistance of the oscillatory circuit which limits the flow of current therein, and this comprises not only the resistance of the loop alone, but also the resistance of the tuning condenser and an effective resistance introduced into the circuit by the attached detector. If a well designed air condenser is used for tuning, the resistance of this element can be neglected. The resistance introduced by the attached detector when this is a vacuum tube is also very small and need not be considered in any but exceptional cases. It can be calculated or determined experimentally by the methods given in Appendix A.

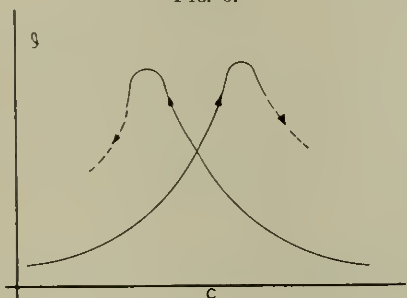
$$R = \frac{R_2 - R_1 \sqrt{\frac{\delta_1}{\delta_2}}}{\sqrt{\frac{\delta_1}{\delta_2}} - 1} - R_T$$

$R_1$ and $R_2$ = different values of inserted resistance.
$\delta_1$ and $\delta_2$ = galvanometer deflections corresponding to $R_1$ and $R_2$.
$R_T$ = resistance of thermoelement.

The average of several values determined in this way for any given set of conditions gives all the accuracy desired.

*Precautions to be Observed.*—In making measurements of this kind it is necessary to arrange the set-up in a large room or out-of-doors and well away from possible absorbing resonators.

FIG. 6.




Proximity of the loop to the walls of a room may result in high effective resistance due to dielectric losses in same. The effect may be considerable, as is shown by one of the tests, when the loop is one of large size and many turns so that there is considerable condenser effect to the walls of the room.

Very loose coupling should be used between the generating and measuring circuits. This point must be carefully watched, for two reasons. First, when the coupling is tight the voltage induced in the loop will change with different inserted resistances.[5] In the second place, there will be two coupling waves, either of which may be tuned to and the results will be inaccurate, due to the impurity of the tuning. Fig. 6 shows the nature of this effect. The coupling should always be made loose enough so that only one hump is present, as in Fig. 7. When the adjustments

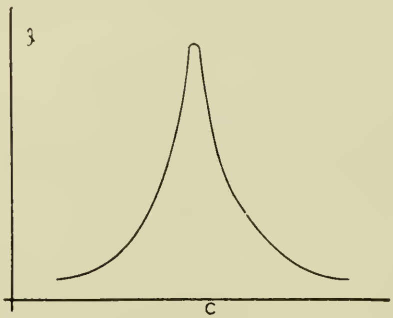
[5] Due to reaction on the exciting circuit.

are properly made an ammeter in the generating circuit will drop only very slightly at resonance. When the coupling is too tight, the reading falls abruptly when the test circuit is brought in tune. The coupling must not be changed during one series of observations on a given wave-length.

The resistance of the thermoelement should be checked occasionally to see that it does not change.

The leads of the loop should be as short as possible, especially for the smaller loops, for in such cases the capacity of the leads may be a large part of the total coil capacity and the resistance will be seriously affected.[6]

Fig. 7.




RESULTS OF LOOP RESISTANCE MEASUREMENTS.

The results of the present experiments are here recorded graphically and in general in two parts.

[6] It might be supposed that the above method would not give entirely accurate results, especially at the shorter wave-lengths, due to the fact that in such cases the current distribution varies through the circuit and is greater near the centre of the loop than at the ends. To test this point a number of resistance measurements were made by another method for verification. In this method the various known resistances were inserted in the circuit to be measured at its electrical centre and the galvanometer with its thermoelement was connected to an auxiliary coil coupled inductively with the loop. With this arrangement the deflections of the galvanometer are practically independent of the current distribution in the loop. When all the proper precautions had been taken it was found that the results obtained by this method checked those obtained by the method described in the text practically exactly.

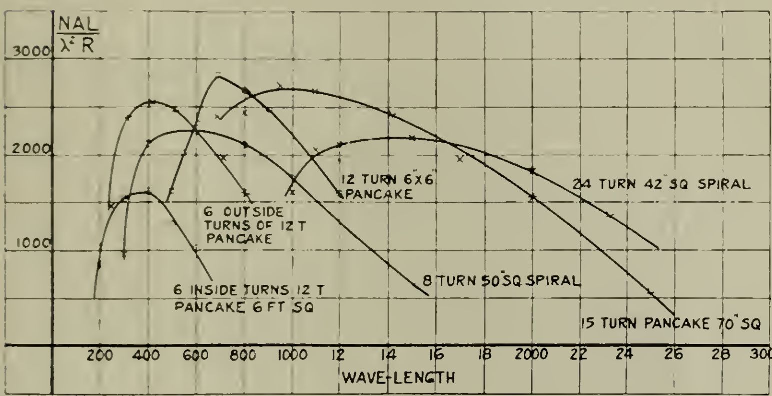
1. The resistance of the loop as function of wave-length.
2. The reception factor as function of wave-length.

The true inductance was estimated from the curve of apparent inductance.

I.

The first set of curves (Fig. 8) show the reception factors

FIG. 8.




of a miscellaneous lot of loops taken at random from loops that had been in use on direction finding experiments. It is interesting to compare these curves with those of some of the later loops in which the best proportions of spacing, diameter, number of turns, etc., were realized. These early loops were relatively inefficient.

The following data are descriptive of this lot of loops:

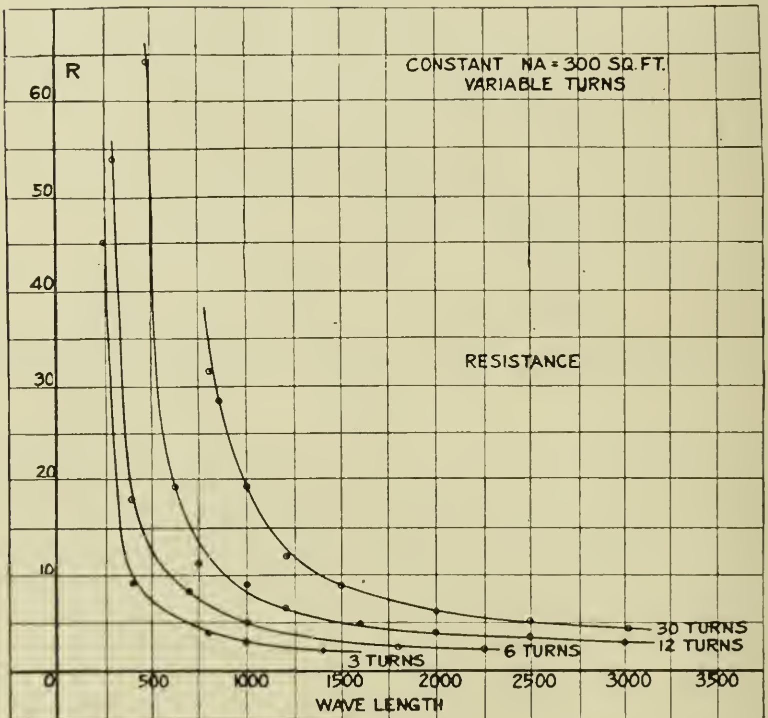
| Loop | L cms. | Description |
|---|---|---|
| 1 | 580,000 | 2 crossed loops at right angles 6 ft. sq. 2″ spacing No. 16 lampcord. |
| 2 | 70,000 | 4 turns bronze antenna wire on 50″ sq., solenoid spacing $\frac{1}{2}$″ |
| 3 | 230,000 | 8 turns same as No. 2. |
| 4 | 94,000 | Inside 6 turns of 12 turn pancake 6 ft. sq., spacing $1\frac{3}{4}$″ stranded No. 18. |
| 5 | 155,000 | Outside 6 of same. |
| 6 | 340,000 | All 12 turns of same. |
| 7 | 800,000 | 15 turn pancake 70″×70″ outside spaced $\frac{3}{16}$″ No. 20 wire. |
| 8 | 2,100,000 | 24 turn 42″ sq. solenoid closely wound litz. 32 No. 38 enameled wires. |

## II.

### CONSTANT FLUX LINKAGES.

As has been shown, the *e.m.f.* induced in a loop depends, among other things, upon the total flux linkages; that is, upon the

Fig. 9.

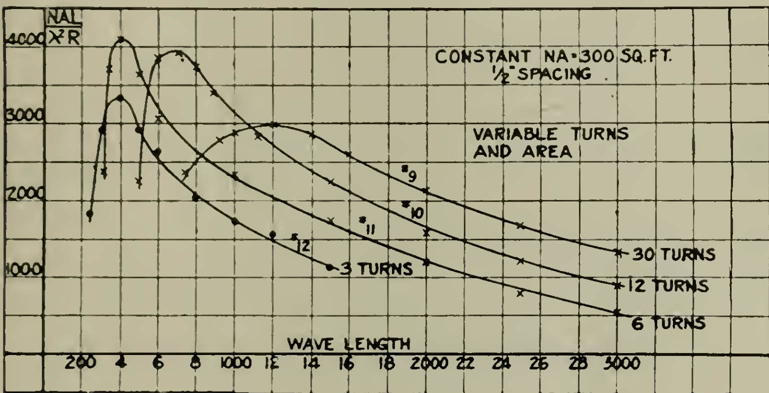



value of the product $NA$. Now it is not immaterial how a given value of this product be obtained. Either a large loop of few turns or a smaller loop of more turns may be used, but the characteristics of the two loops are widely different.

This is well shown by the curves of Figs. 9 and 10, which give the resistance and reception factor for 4 different loops whose size and number of turns were varied in such a way as to keep the product $NA$ constant.

It will be seen from Fig. 10 that for short wave-lengths it is better to use large loops of a few turns, while for long waves smaller loops having more turns are preferable. This general conclusion is important and should never be lost sight of, although, as will be seen later, there finally comes a time at very long wave-

FIG. 10.




lengths when it is again better to decrease the turns and increase the size.

The 4 loops just mentioned have the following constants:

| Loop | Turns | Area, sq. ft. | Spacing | Type | L cms. |
|---|---|---|---|---|---|
| 9 | 30 | 10 | ½" | Solenoidal | 1,250,000 |
| 10 | 12 | 25 | ½" | Solenoidal | 582,000 |
| 11 | 6 | 50 | ½" | Solenoidal | 280,000 |
| 12 | 3 | 100 | ½" | Solenoidal | 120,000 |

## III.

### CONSTANT INDUCTANCE.

In proportioning a receiver for given wave-length, it is always best to use small tuning condensers, because this offers the possibility of large loop inductance (turns and area). A given inductance may be obtained either by few turns on a large frame or many turns on a small frame. There is a difference, however, as regards the relative effectiveness in the two cases.

Figs. 11 and 12 show the results of a comparison of several

Fig. 11.

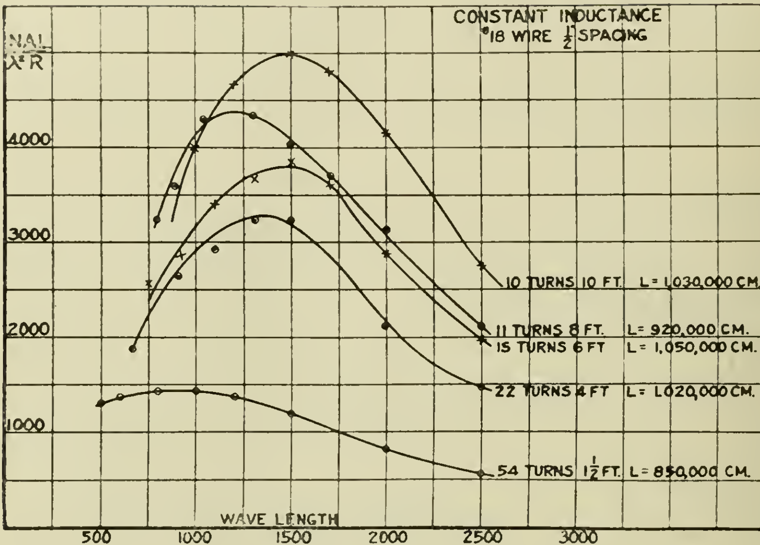
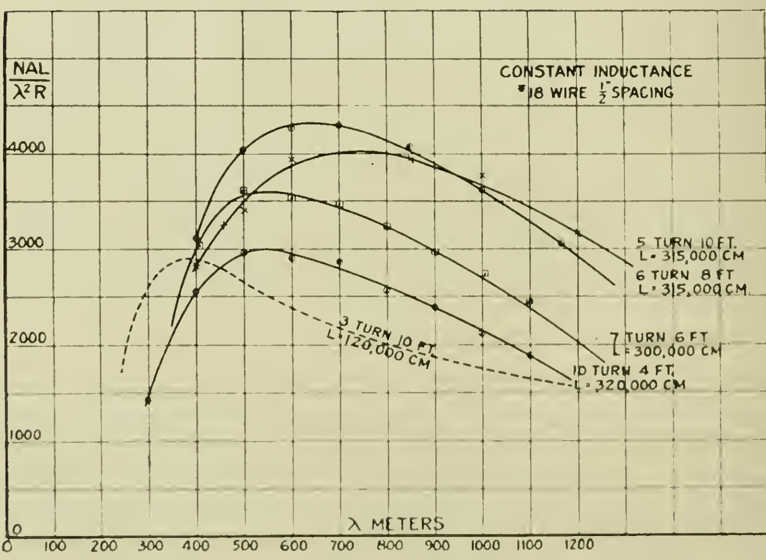

CONSTANT INDUCTANCE
#18 WIRE ½" SPACING
NAL / λ²R
4000
3000
2000
1000
10 TURNS 10 FT. L = 1,030,000 CM.
11 TURNS 8 FT. L = 920,000 CM.
15 TURNS 6 FT L = 1,050,000 CM.
22 TURNS 4 FT L = 1,020,000 CM.
54 TURNS 1½ FT. L = 850,000 CM.
WAVE LENGTH
500 1000 1500 2000 2500 3000

Fig. 12.


NAL / λ²R
CONSTANT INDUCTANCE
#18 WIRE ½" SPACING
4000
3000
2000
1000
0
5 TURN 10 FT. L = 315,000 CM
6 TURN 8 FT L = 315,000 CM.
3 TURN 10 FT L = 120,000 CM
7 TURN 6 FT L = 300,000 CM
10 TURN 4 FT. L = 320,000 CM
λ METERS
0 100 200 300 400 500 600 700 800 900 1000 1100 1200

coils in which the number of turns and the area of the loops were varied, but in such a way as to maintain the inductance approximately constant. It will be seen that in this case the maximum reception factor always occurs at approximately the same wave-length, regardless of whether the given inductance is obtained by few turns and large area or the reverse. The curves become flatter as the number of turns increases, which means that a coil of many turns responds efficiently over a wider range of wave-lengths than does one of a few turns.

This last statement has direct application to small tuning coils as well; for example, the secondary of the ordinary loose-coupler. The general theory outlined above holds exactly for this case, and the same type of characteristics may be obtained for such coils.

While the data of this test does not cover very large loops of only one or two turns and so cannot be interpreted for such extreme cases, it does show that within the range used it is better for given inductance to use large loops with few turns. It would appear that for given inductance a single turn very large loop would be best, as the total flux $(NA)$ would then be maximum.

## IV.

### DETERMINATION OF BEST SPACING.

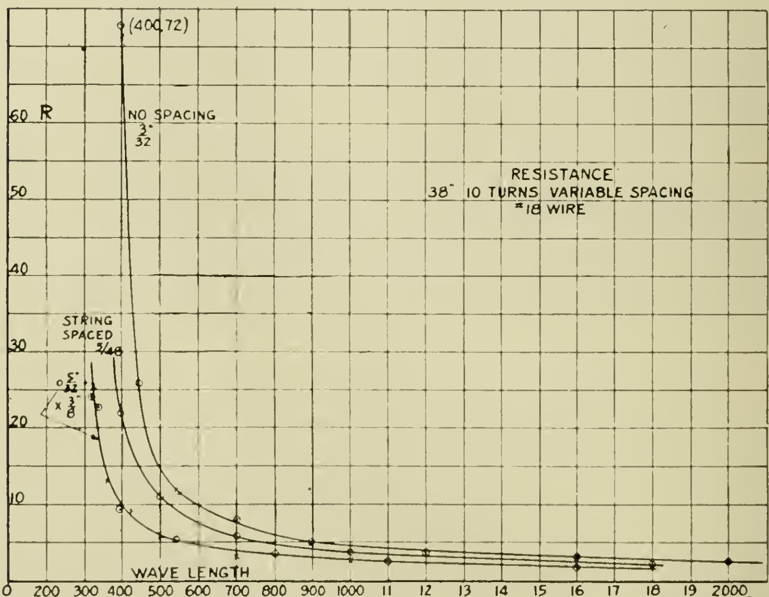
The spacing of the turns is a most important factor. Except at very long wave-lengths a closely wound coil has much higher resistance than one on which the turns are spaced. It is, therefore, better to space the winding unless the coil is to be used for extremely long wave-lengths. It is actually better in this case not to separate the wires very much because of the sacrifice in inductance.

For a given size of loop and given number of turns, *i.e.*, constant flux linkages, we have two opposing effects resulting from an increase in spacing, the decrease in self-inductance *vs.* the decrease in resistance. At first, the resistance decreases more rapidly than the inductance, so that increasing the spacing is for a time advantageous. A point is soon reached, however, where further increase in spacing affects the resistance very little, and this point should not be exceeded; for the inductance still falls off and the reception factor is therefore lowered.

If the inductance is kept constant by adding turns as the spacing increases, the best value of spacing is, of course, not so sharply defined, but still exists and corresponds to the point where the resistance ceases to be appreciably affected. It coincides very closely with the best value as determined for constant turns.

The nature of the several effects just mentioned is shown in Figs. 13, 14, 15, 16, 17, 18, 19, 20. Figs. 13, 15, 17, 19 show the resistance as function of wave-length for various sizes of coils

FIG. 13.




(3, 6, 10, 15 ft.) wound with 10 turns of No. 18 wire and spacing systematically varied. Figs. 14, 16, 18, 20 show the corresponding reception factor curves. A best value of spacing is clearly evidenced in each case. Figs. 13-A and 15-A are given to show the effect of spacing on inductance and should be studied in conjunction with the resistance curves for the same loops (Figs. 13 and 15).

It will be noticed that in general the closer the spacing the greater is the useful range of wave-lengths of the loop. Wide spacings make the reception factor curve peaked. It is, therefore,

FIG. 13A.

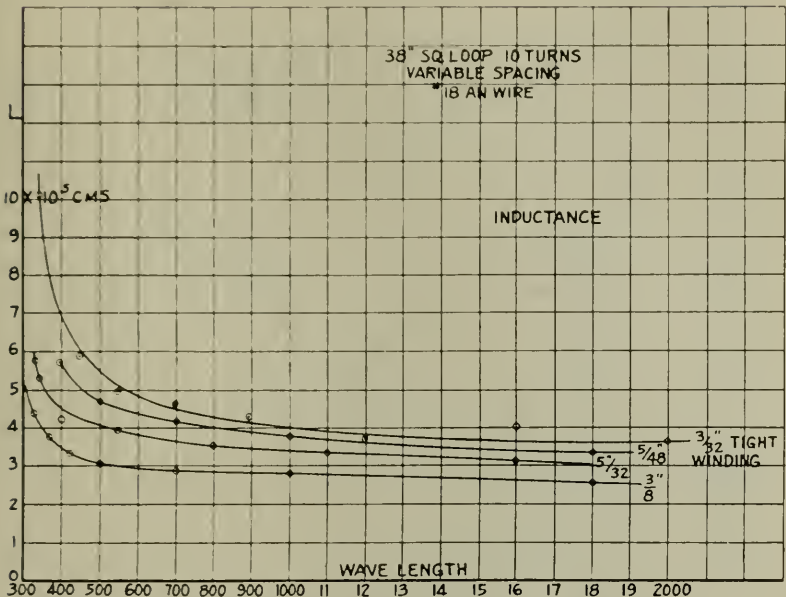



FIG. 14.

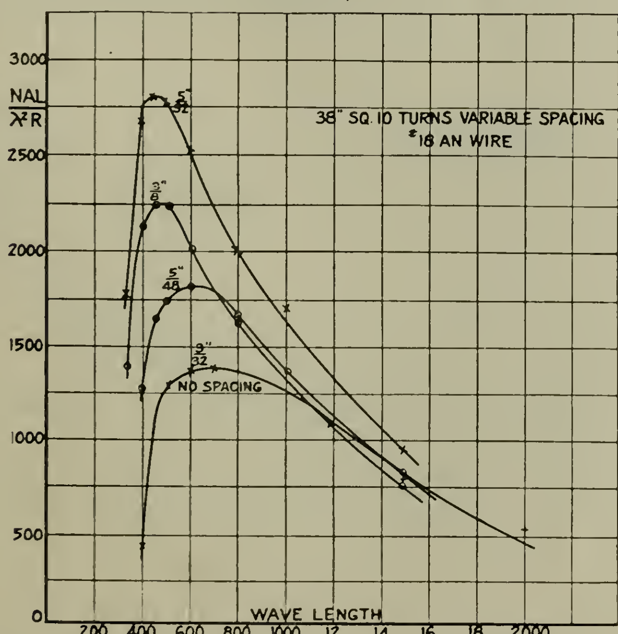


FIG. 15.

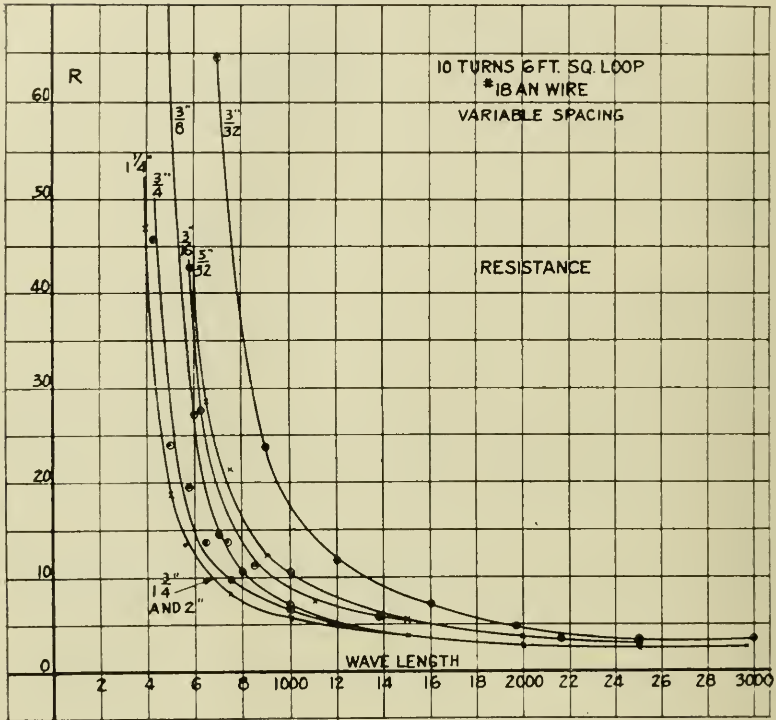



FIG. 15A.

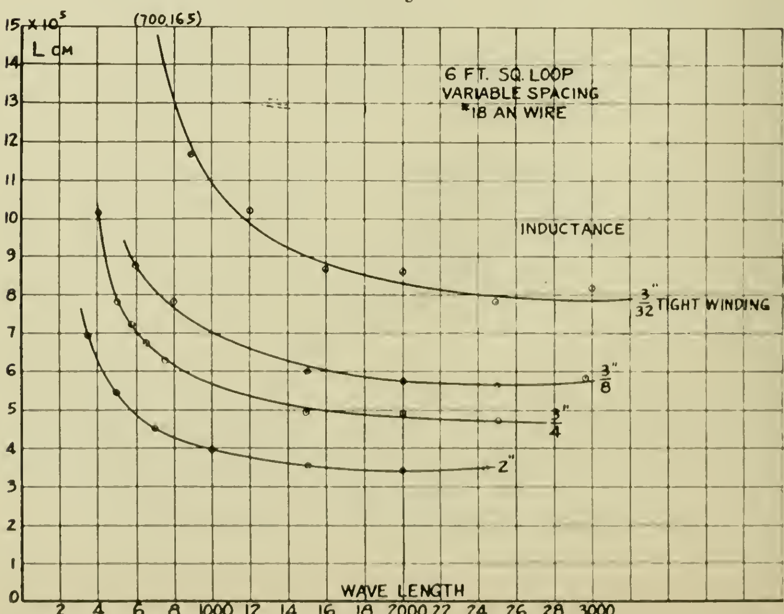


FIG. 16.

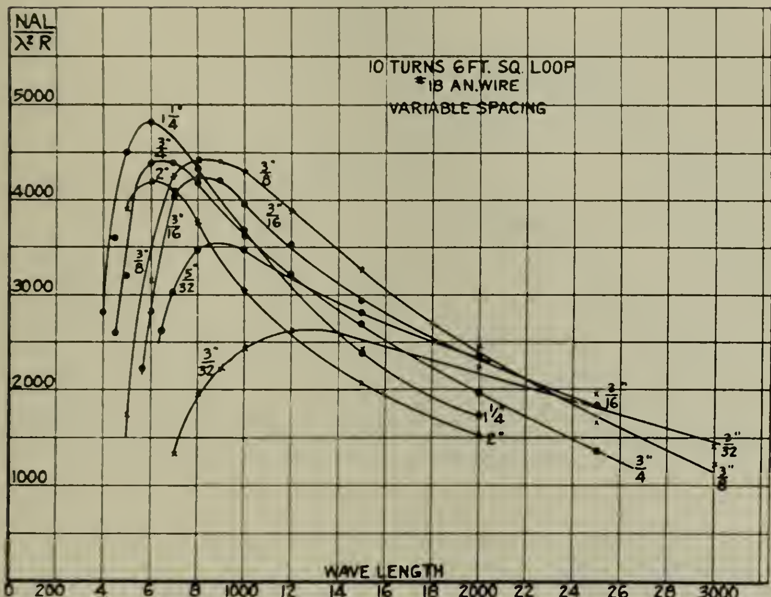

NAL / λ²R
10 TURNS 6 FT. SQ. LOOP
*18 AN. WIRE
VARIABLE SPACING
WAVE LENGTH

FIG. 17.

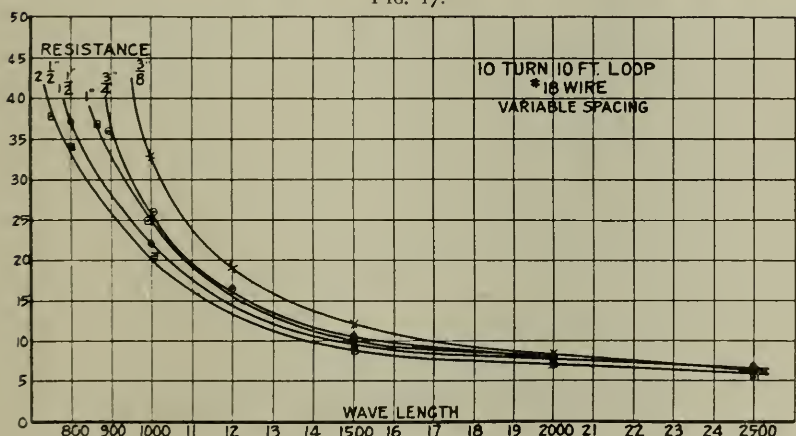

RESISTANCE
10 TURN 10 FT. LOOP
*18 WIRE
VARIABLE SPACING
WAVE LENGTH

Fig. 18.

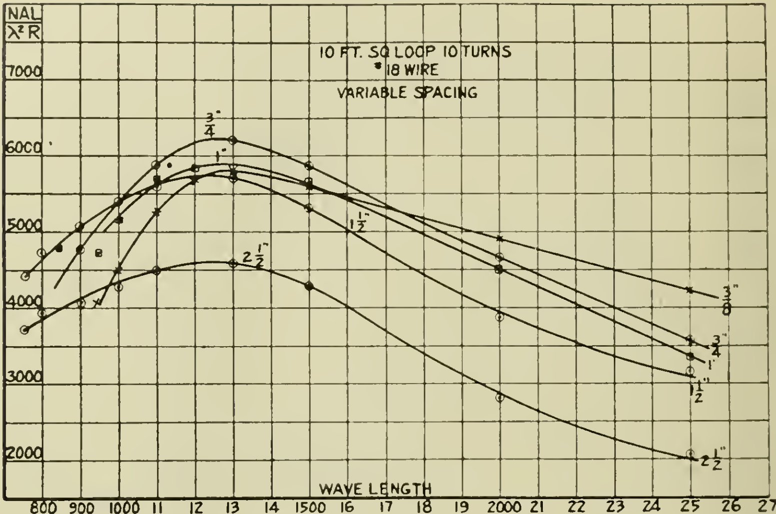

NAL
λ² R
10 FT. SQ LOOP 10 TURNS
# 18 WIRE
VARIABLE SPACING
7000
6000
5000
4000
3000
2000
WAVE LENGTH
800 900 1000 11 12 13 14 1500 16 17 18 19 2000 21 22 23 24 25 26 27

Fig. 19.

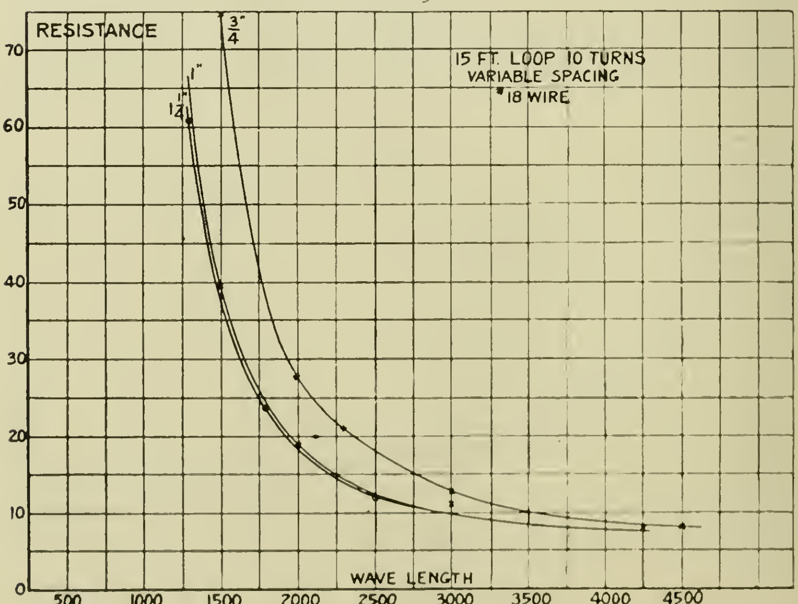

RESISTANCE
15 FT. LOOP 10 TURNS
VARIABLE SPACING
# 18 WIRE
70
60
50
40
30
20
10
0
WAVE LENGTH
500 1000 1500 2000 2500 3000 3500 4000 4500

Fig. 20.

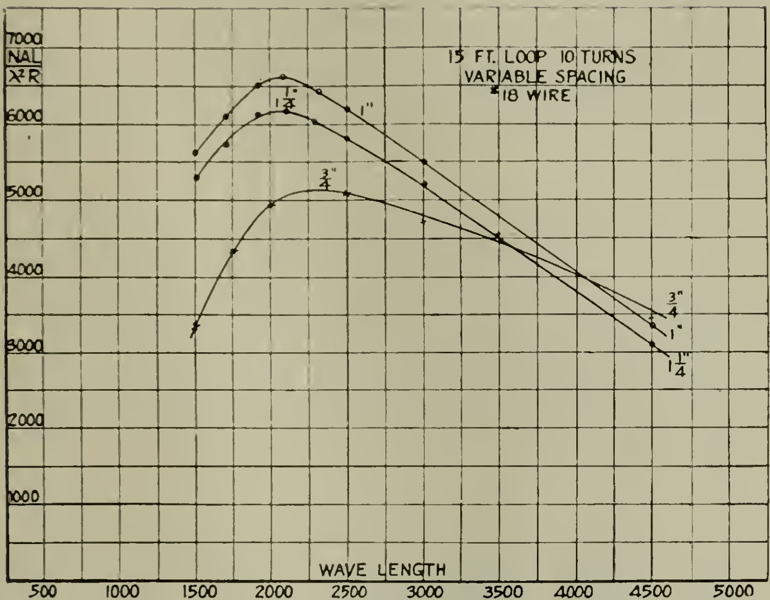
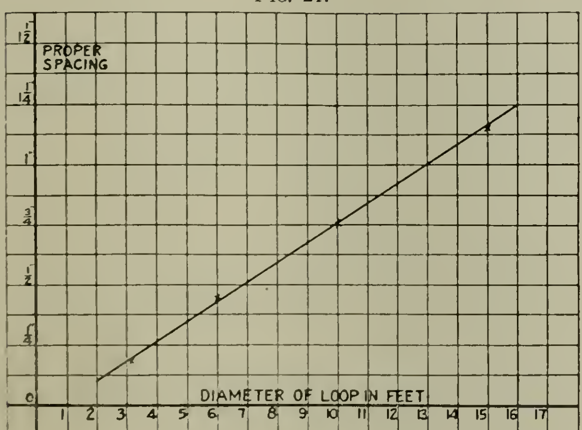

7000
NAL
$\lambda^2R$
15 FT. LOOP 10 TURNS
VARIABLE SPACING
#18 WIRE
1"
$1\frac{1}{4}$"
$\frac{3}{4}$"
1"
$1\frac{1}{4}$"
WAVE LENGTH
500 1000 1500 2000 2500 3000 3500 4000 4500 5000

Fig. 21.


PROPER
SPACING
$1\frac{1}{2}$
$1\frac{1}{4}$
1"
$\frac{3}{4}$
$\frac{1}{2}$
$\frac{1}{4}$
0
DIAMETER OF LOOP IN FEET
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

necessary to choose the best spacing not simply as that which gives the highest maximum in the reception factor curve but the sharpness of this curve should also be considered. The effectiveness of the loop ought not to fall away too quickly as the wave-length changes from the best value.

The curves show that the natural period of the coil and correspondingly the best wave-length is lowered by increased spacing. This effect is most pronounced for changes in the spacing when the latter is small.

The best spacing has been determined for four different sizes of loop, *viz.*, 3 ft., 6 ft., 10 ft., 15 ft. (Figs. 14, 16, 18, 20), and there appears to be a direct proportionality between size of loop and best spacing. Thus, when the best spacing is plotted against size of loop the straight line relation of Fig. 21 is obtained. It would seem that the capacity between turns is a most important factor, since this also increases directly with the linear dimensions of the loop. The data of Fig. 21 are very useful in designing loops.

V.

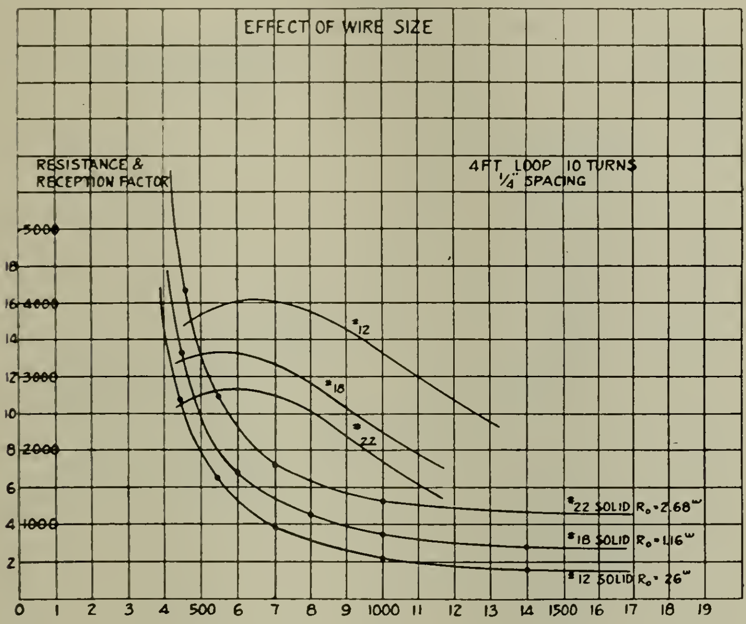
EFFECT OF SIZE AND KIND OF WIRE.

For the wires ordinarily used, that is, from say No. 22 to No. 14 B. & S. gauge, the size of the wire has little influence on the best spacing as determined above. In general, large wires should be spaced farther apart than small ones, but this effect is only pronounced when the spacing is so small as to be comparable with the diameter of the wire itself. For given spacing under these conditions it may actually be better to use smaller wire so as to make the ratio of wire diameter to spacing less. This is particularly true for short or moderate wave-lengths. For very long waves the resistance approaches its *d.c.* value and the smaller wire in that case offers no advantage.

Fig. 22 gives the resistance curves for three 10 turn coils wound on a 4 ft. frame with ¼″ spacing, using three different sizes of wire, No. 22, No. 18, No. 12. It will be noticed that at short wave-lengths the resistance depends very little on the size of the wire, while for longer wave-lengths the curves separate more and more and are controlled by the *d.c.* resistance in each case. This figure also shows the reception factor curves for the three coils just mentioned, and it is seen that the best wave-length for a given coil is independent of the size of wire with which it is wound.

There is some advantage, of course, in the matter of efficiency if the size of wire is greatly increased. This is not so great as might be at first imagined, however; for in the first place, the effect of *d.c.* resistance on the total effective resistance in the neighborhood of best working wave-length is of rather secondary order, and in the second place, the inductance of the large wire coil is less than that of a coil using fine wire so that the reception

FIG. 22.




factor $NAL/\lambda 2r$ is prevented from increasing as rapidly as would be indicated by variation in resistance alone.

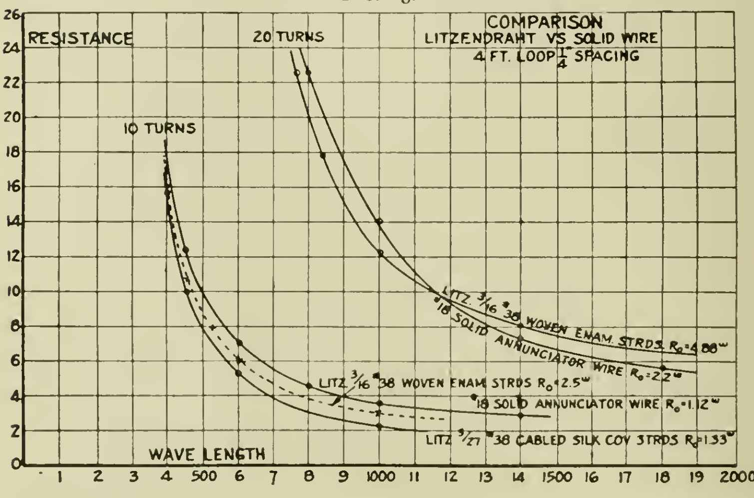
*Litzendraht.*—In order to compare the relative efficiency of solid wire with that of litzendraht and stranded wire the curves of Fig. 23 were taken. Two different size coils were compared, one of 10 turns and one of 20 turns. Both were on frames 4 ft. square and the spacing was ¼". For the 20 turn loop No. 18 solid wire was compared with litzendraht having about 45 per cent. of the equivalent cross-section and composed of three bundles of sixteen No. 38 enameled wires each. The separate strands

were woven criss-cross, in and out, in such a way as to form a sort of tubular conductor.

For the 10 turn loop the same wire was compared with the No. 18 solid, and in addition a stranded conductor having approximately the same cross-section as the No. 18 was also used. This latter consisted of three bundles of twenty-seven No. 38 silk-covered strands each; but instead of being woven the separate strands were simply cabled together in a long spiral.

The curves show that the asymtotic rise in resistance at short

Fig. 23.



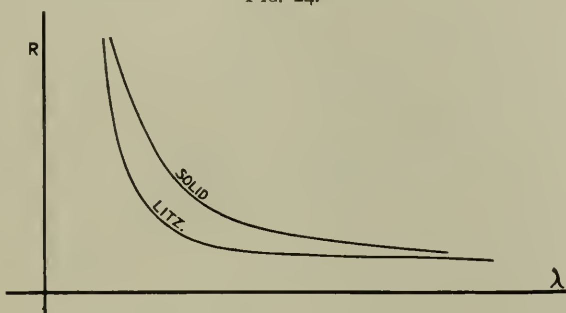

wave-lengths is much more abrupt with stranded wire and litzendraht than with solid wire. At short waves there is very little advantage in the use of litzendraht over solid wire for a given total cross-section; and the same is true for very long waves, because the resistance for both wires is approaching the same *d.c.* value. But for intermediate wave-lengths the stranded wire or litzendraht is better. Fig. 24 shows the nature of the effect on an exaggerated scale.

If the litzendraht has less cross-section than the solid wire, then the two curves will cross (see Fig. 23) and we then have the interesting conclusion that for wave-lengths above a certain value the solid wire has less resistance than the litzendraht and is therefore better, while below this wave-length the litzendraht

should be used. Or it may result that the two curves practically coincide for a portion of their length and thus the use of litzendraht or solid wire is immaterial.

*Effect of Insulation Covering.*—When the wires are wound tightly together there are losses in the dielectric between turns, that is, in the insulation, which raises the effective resistance of the coil. When the wires are spaced several diameters, however, it is immaterial whether they be insulated or bare. Thus, the resistance curve of a 10 turn coil of No. 18 bare wire spaced ¼″ on a 4 ft. frame was compared with those of similar coils of No. 18 d.c.c. white and No. 18 d.c.c. paraffined blue wires. The three curves coincided perfectly.

FIG. 24.




The reason for comparing the blue insulated wire was that an analysis of the insulation showed the coloring matter to contain iron salt (ferro-ferri-cyanide) which it was thought might be magnetic and therefore affect the overall resistance. It must be concluded that coloring matter has little or no effect on the resistance, at least for the spacings used.

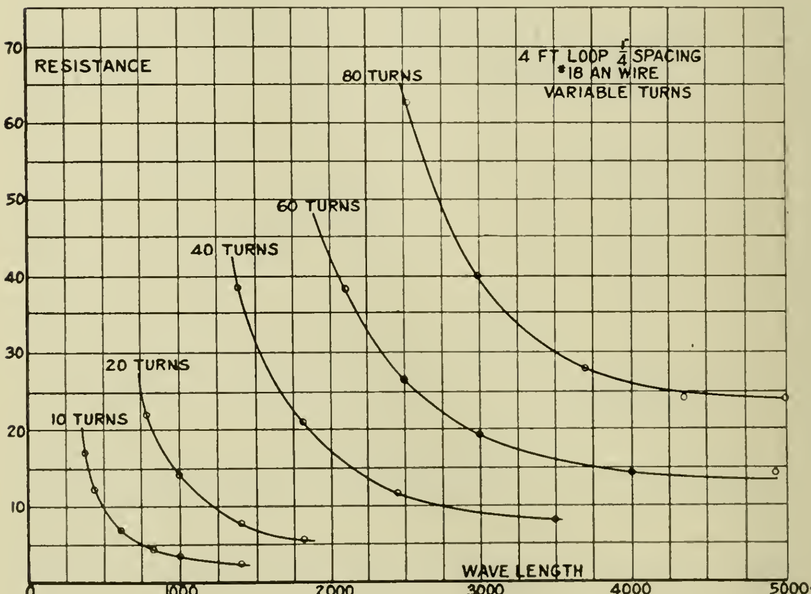
## VI.

### DETERMINATION OF BEST SIZE OF LOOP AND NUMBER OF TURNS FOR GIVEN WAVE-LENGTH DESIGN CHART.

The results of Sections 2 and 3 above show that for given inductance it is best to use for $N$ the minimum and for $A$ the maximum, while for given flux linkages the best values of $N$ and $A$ depend on the wave-length. Combining these conclusions we

can see that there are certain best proportionings of flux linkages and inductance. The problem is somewhat as follows: Given a certain wave-length, a small value of tuning capacity may be assumed and the required inductance calculated. This may be obtained by the use of a few turns on a large frame or many turns on a small frame. Now, at first sight it would seem as though the combination using few turns and large diameter would be best because this gives highest flux linkages [7] (Sect. 3). But, as

FIG. 25.




shown in Sect. 2, such disposition lowers the natural wave-length of the coil and hence the best working wave-length. For given wave-length, therefore, there are certain proportions of inductance and total area $NA$ which give best results.

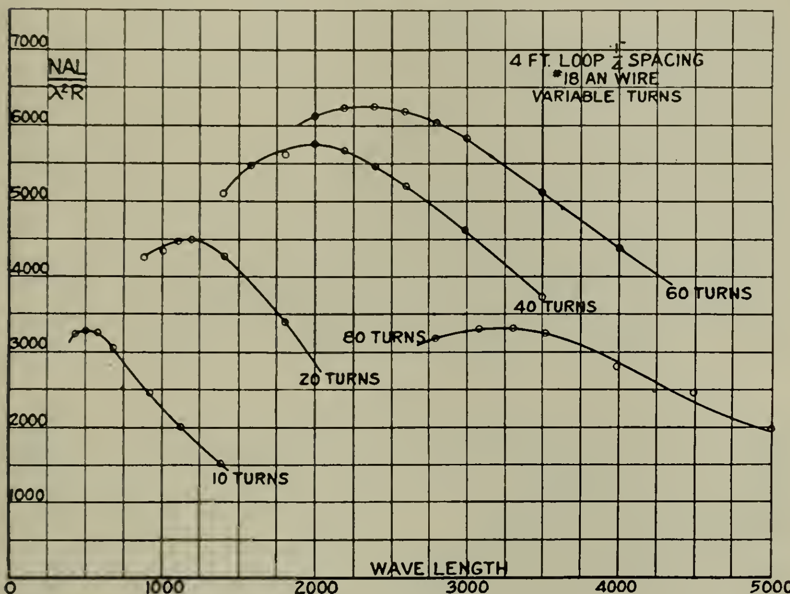
In order to work out these relations, resistance curves were taken and reception factor curves calculated therefrom for different sizes of loops and different numbers of turns. The spacing

[7] $L$ varies as square of turns but only directly as the area. Flux linkages are proportional to $NA$. Hence for constant $L$ large area and few turns give larger flux linkages than many turns and small area.

in each case was that best value, as read from Fig. 21 of Sect. 4, corresponding to the size of the loop used. The wire was No. 18 d.c.c. annunciator (solid).

Figs. 25 and 26 refer to 4 ft. loops, ¼″ spacing with turns varied from 10 to 80; Figs. 27 and 28 to 6 ft. loops 7/16″ spacing; Figs. 29 and 30 to 10 ft. loops ¾″ spacing; and Figs. 31 and 32

FIG. 26.




to 15 ft. loops with 1⅛″ spacing. For this series the 4 ft., 6 ft., and 10 ft. loops were mounted horizontally in a large room, so that the edges of the loop were as far from the walls as possible. The minimum clearance in the case of the 10 ft. loop was 6 ft. The 15 ft. loop was built out-of-doors and the lower edge was 5 ft. from the earth.

Two important facts are shown by these curves. The first is that as the number of turns is increased the maximum in the reception factor curves becomes less sharply defined and the loop receives efficiently over a comparatively greater wave-length range. The second important feature is that as the number of turns on a given frame is continuously increased the maximum

FIG. 27.

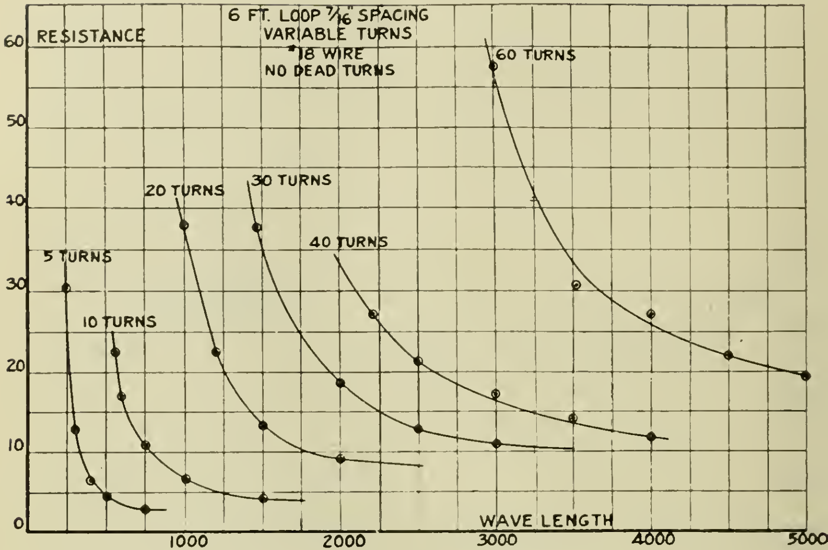

6 FT. LOOP 7/16" SPACING
VARIABLE TURNS
#18 WIRE
NO DEAD TURNS
RESISTANCE
60
50
40
30
20
10
0
5 TURNS
10 TURNS
20 TURNS
30 TURNS
40 TURNS
60 TURNS
WAVE LENGTH
1000
2000
3000
4000
5000

FIG. 28.

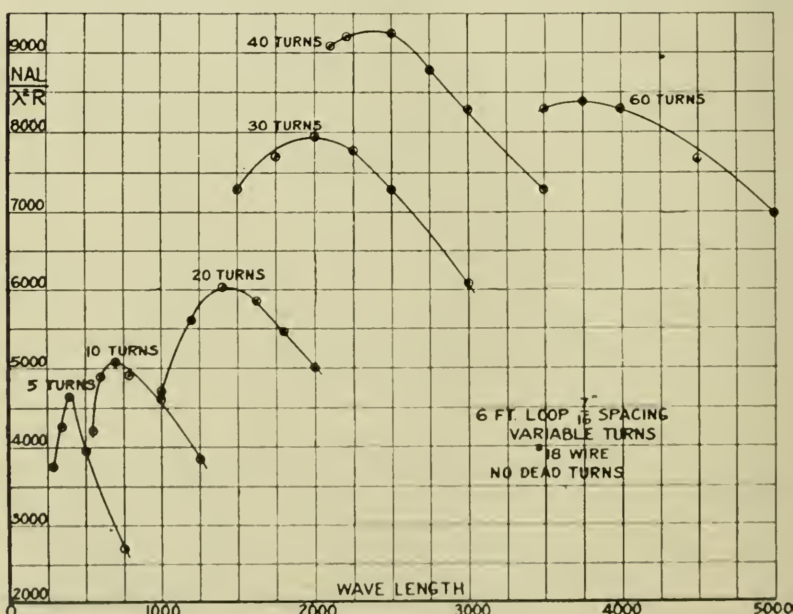

9000
NAL
λ²R
8000
7000
6000
5000
4000
3000
2000
0
40 TURNS
30 TURNS
60 TURNS
20 TURNS
10 TURNS
5 TURNS
6 FT. LOOP 7/16" SPACING
VARIABLE TURNS
#18 WIRE
NO DEAD TURNS
WAVE LENGTH
1000
2000
3000
4000
5000

FIG. 29.

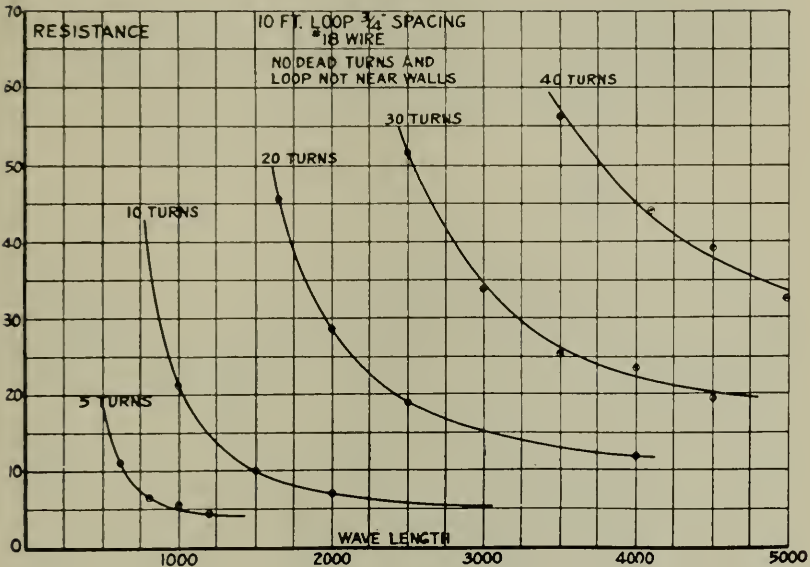
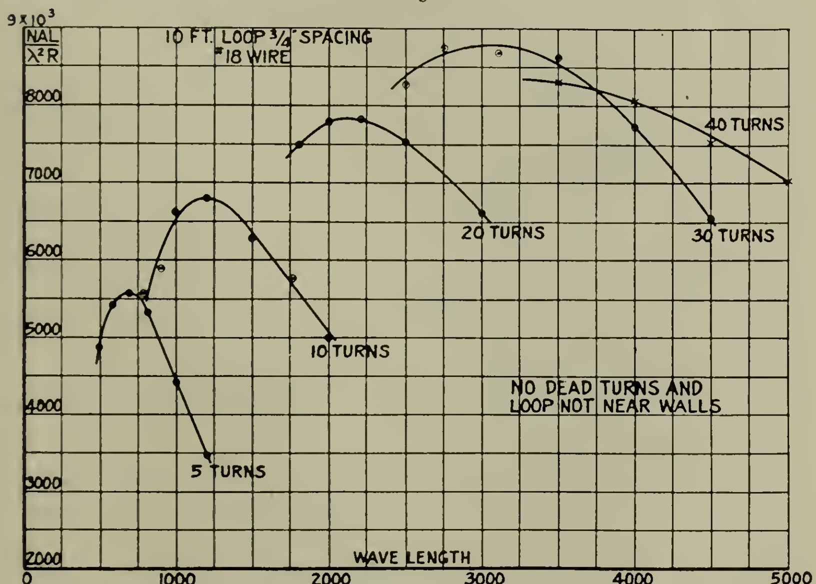

RESISTANCE
10 FT. LOOP 3/4" SPACING
#18 WIRE
NO DEAD TURNS AND
LOOP NOT NEAR WALLS
40 TURNS
30 TURNS
20 TURNS
10 TURNS
5 TURNS
WAVE LENGTH
70
60
50
40
30
20
10
0
1000
2000
3000
4000
5000

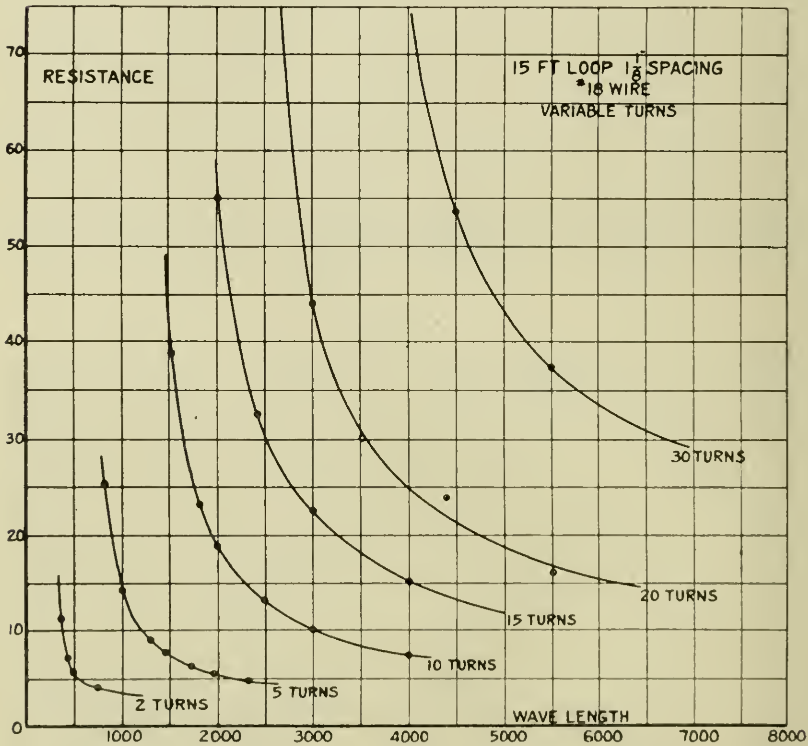
FIG. 30.


9 x 10^3
NAL
λ²R
10 FT. LOOP 3/4" SPACING
#18 WIRE
8000
7000
6000
5000
4000
3000
2000
40 TURNS
30 TURNS
20 TURNS
10 TURNS
5 TURNS
NO DEAD TURNS AND
LOOP NOT NEAR WALLS
WAVE LENGTH
0
1000
2000
3000
4000
5000

reception factor increases, reaches a maximum, and then falls off. The highest efficiency for a 4 ft. loop occurs with about 50 turns, while for 6 ft., 10 ft., and 15 ft. loops it is less, and about as shown in the following table.

| Size of loop | No. turns for best possible reception |
|---|---|
| 4 feet | 52 |
| 6 feet | 45 |
| 10 feet | 30 |
| 15 feet | 25 |

FIG. 31.

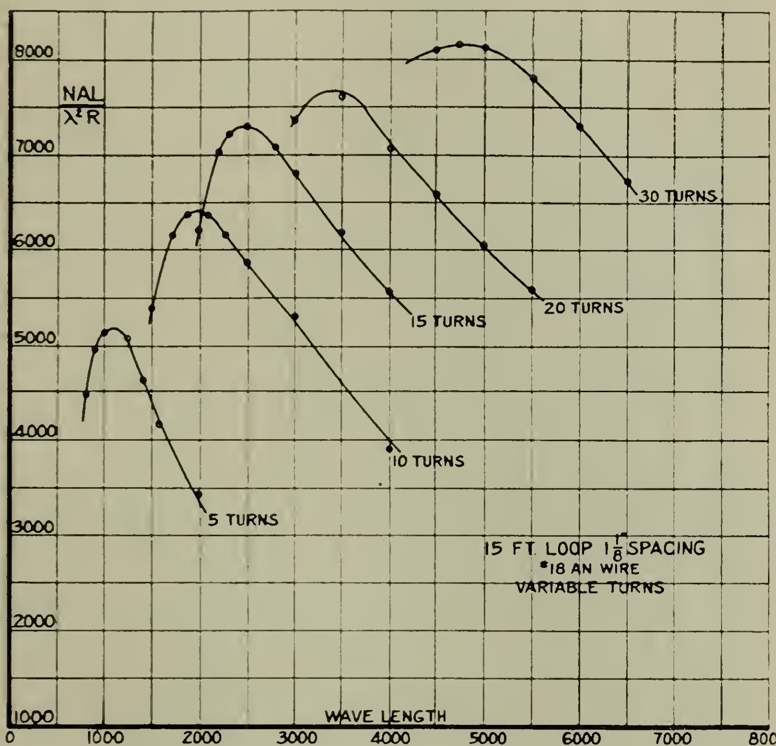



For a given number of turns and given size of loop there is one best wave-length at which to operate. This wave-length may be read off from the curves of Figs. 26, 28, 30, 32 and plotted directly against turn ($N$) with size of loop as parametre. This has been done in the lower part of Fig. 35, which, therefore, gives correlated optimum values of turns, size of loop and wave-length.

The 8 ft. and 12 ft. curves were interpolated by plotting values of $\lambda$ against size of loop through several different ordinates of $N$.

The upper curves of Fig. 33 were also obtained from Figs. 26, 28, 30 and 32 by plotting the maximum reception factors indicated therein against the corresponding number of turns.

FIG. 32.



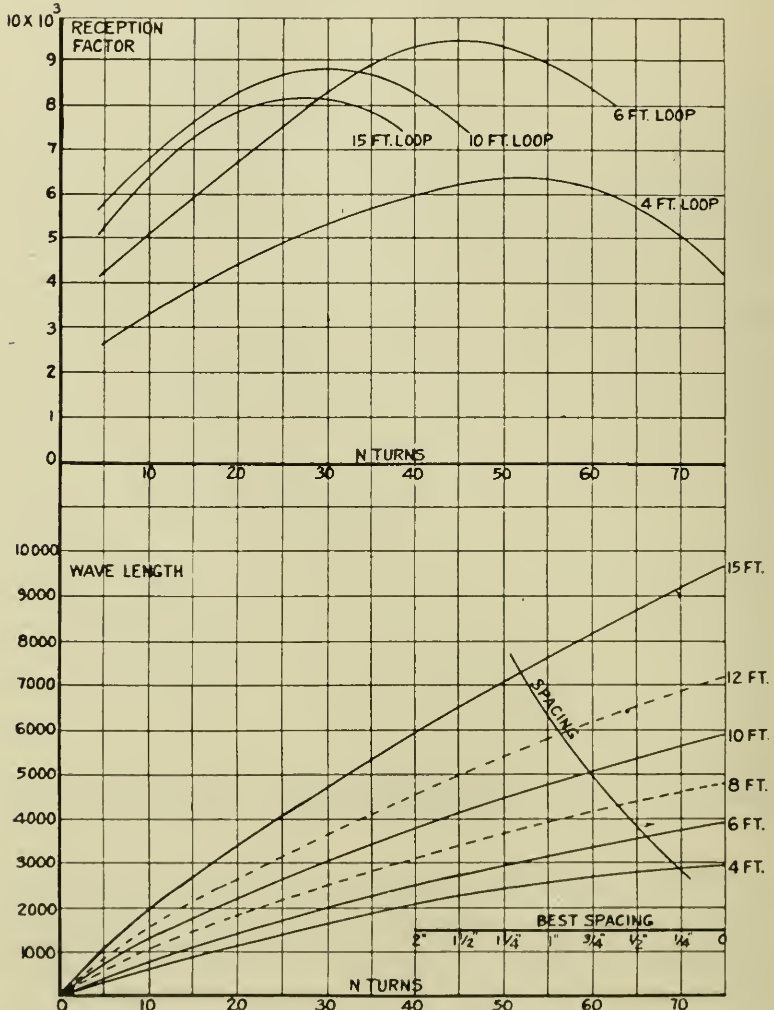

The spacing curve of this figure was drawn from the data of Fig. 21, and thus Fig. 33 becomes a complete working chart which may be used for designing loops of maximum efficiency at any chosen wave-length.

Data of a similar nature to the above, but referring particularly to short wave-lengths (200 metres to 1000 metres), have been taken, but is omitted here because of lack of space.

EXAMPLES OF THE USE OF DESIGN CHART.

As an example of the use of the design chart, let it be required to determine the elements of a loop for receiving a wave-length

Fig. 33.




of 1500 metres. The chart shows the following possible combinations:

| Size of loop | No. of turns | Spacing |
|---|---|---|
| 15 feet | 7 | 1⅛″ |
| 10 feet | 13 | ¾″ |
| 6 feet | 22 | $\frac{7}{16}$″ |
| 4 feet | 27 | ¼″ |

In order to determine which of these is the best, reference is made to the upper reception factor curves. This gives the following data:

| Size of loop | Reception factor |
|---|---|
| 15 feet | 5700 |
| 10 feet | 7300 |
| 6 feet | 7000 |
| 4 feet | 5000 |

The 10 ft. 13 turn loop is the best, although a somewhat smaller loop down to 6 ft. may be used without serious disadvantage.

As a second example, let the required working wave-length be 3000 metres. The following set of values will be found:

| Size of loop | No. of turns | Spacing | Reception factor |
|---|---|---|---|
| 15 feet | 17 | 1⅛″ | 7500 |
| 10 feet | 30 | ¾″ | 8800 |
| 6 feet | 50 | $\frac{7}{16}$″ | 9300 |
| 4 feet | 78 | ¼″ | 4000 |

It thus appears that in this case a 6 ft. 50 turn loop is best.

## SIZE OF TUNING CONDENSER.

To complete the design of the receiving system it is necessary to know the size of tuning condenser needed for the loop and wave-length in question. This information can be had directly when the apparent inductance of the given loop is known at different wave-lengths. Data of this sort has been taken for all of the loops described above, though lack of space prevents its inclusion in this paper. The important result obtained from the data is that any loop can be worked at its best wave-length by the use of a variable condenser having a maximum capacity not exceeding 0.001 mf.

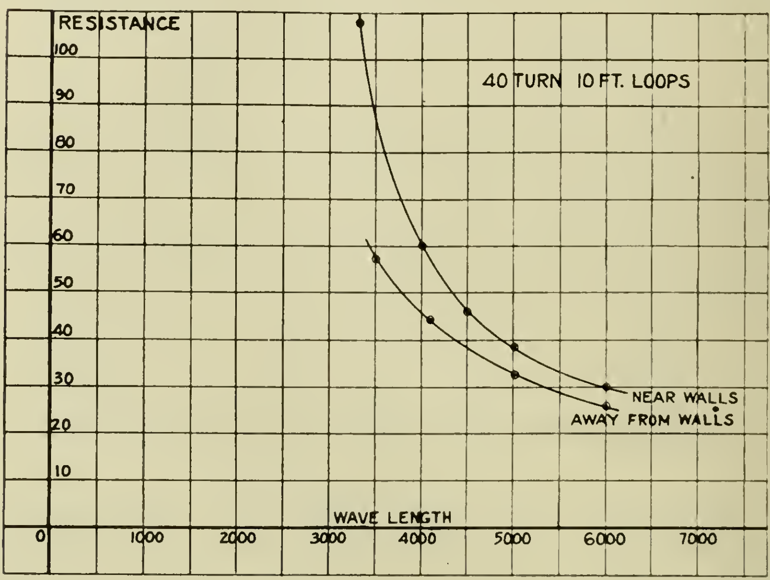
## EFFECT OF DEVIATION FROM BEST WAVE-LENGTH.

If, as is often the case, a loop is to be used at several wave-lengths rather than at one fixed value, then the design chart (Fig. 33) does not tell the whole story. In this case reference should also be made to Figs. 26, 28, 30, 32 in order to choose a loop which gives the best *average* efficiency over the desired range of wave-lengths.

EFFECT OF PROXIMITY TO WALLS OF ROOM.

When a loop is used indoors, proximity to the walls or ceiling and floor of the room may cause the appearance of higher effective resistance than otherwise. The magnitude of this effect is shown in Fig. 34. Curve *A* gives the resistance of a 40 turn

Fig. 34.




10 ft. square loop with ¾″ spacing when placed vertically in a second-floor room, the upper and lower edges being 6″ from ceiling and floor, respectively. The ceiling was plaster, the floor concrete. Curve *B* is for the same loop placed horizontally in the centre of the room with a minimum distance of about 5 ft. from walls, ceiling and floor. The resistance is considerably lower in the latter case.

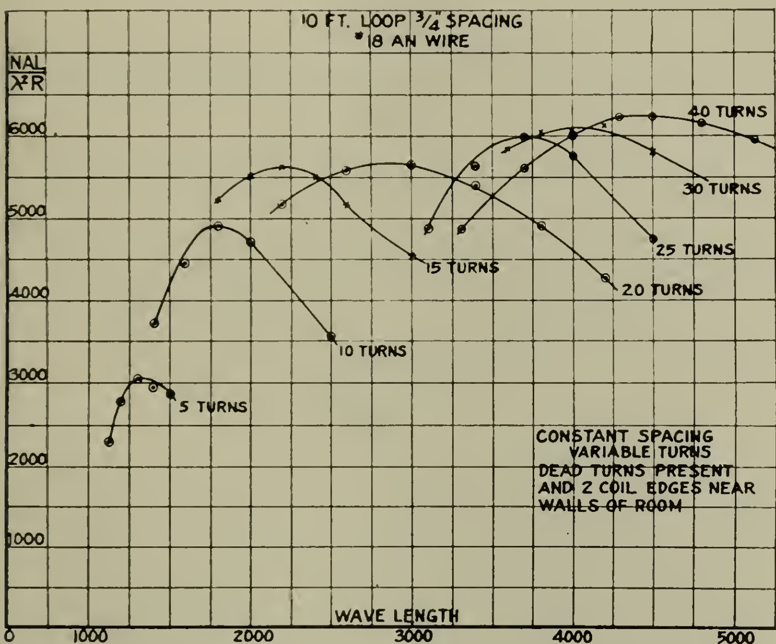
EFFECT OF DEAD TURNS.

The effect of leaving overhanging dead turns on the loop is shown in Fig. 35, which shows the reception factor as function of wave-length. The neighboring imperfect dielectric effect described in a previous paragraph is also present here, as the loop was used vertically with lower and upper edges near floor and

ceiling. The dead turns were broken into sections of 10 turns each, except for the measurement of 5 turns when there was an adjacent 5 turn section.

The exact nature and magnitude of the dead-end effect is much more vividly presented by superposing Fig. 35 on Fig. 30. It may be seen that in general the dead turns materially reduce the efficiency of the used portions of the loop. In fact, so great

FIG. 35.




is this effect on short wave-lengths that the best wave-length is actually much longer (shifted to the right) when there are dead turns present.

## GENERAL REMARKS.

The working curves of the last section apply accurately only to loops wound with No. 18 solid wire. However, if wire of different size is used the interrelation of best wave-length, turns, spacing, and size of loop is not appreciably changed, but only the efficiency varies, and it is either decreased or increased for all wave-lengths. This was definitely shown by the data of Sect. 5.

All the reception factor curves are based on sustained wave reception and a detector response proportional to the *effective* undamped voltage across the loop condenser. If damped waves are being received the efficiency is different and, in general, the best wave-length for a given loop is shifted slightly toward shorter values. The reason for this is that for damped waves the reception is a function of transmitter and receiver decrements such that the inverse proportionality of current to loop resistance is not exact.

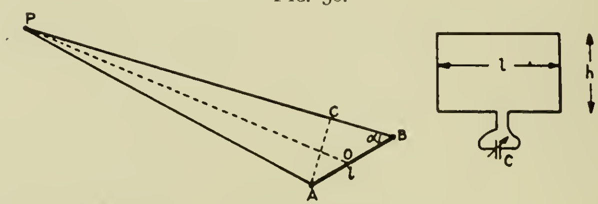
## PART II.

### THE DIRECTIONAL CHARACTERISTICS OF LOOP RECEIVERS.

#### GENERAL.

In Fig. 36 is shown a loop receiver of height $h$ and breadth $l$

FIG. 36.




turned at angle $\alpha$ (in azimuth) to the line of propagation of waves originating at $P$. There are supposed to be $N$ turns of wire on the loop wound close together, so that at any instant all of the wires on a given edge of the loop $A$ or $B$ occupy sensibly the same place in the wave field; in other words, the winding here is not spaced.

It is further assumed that the wave front at the receiver is plane and perpendicular to the earth's surface.

Let $e = E \sin \omega t$ = electric field intensity at $O$ produced by $P$.

The field at $B$ lags that at $A$ by $\phi$ times degrees.

$$\Phi = \frac{PB - PA}{\lambda} 2\pi \text{ and since } PC \cong PA$$

$$\Phi = \frac{BC}{\lambda} 2\pi = \frac{2\pi l}{\lambda} \cos \alpha$$

At $B$ the electric field (referred in time to o) is:

$$e_b = E \sin\left(\omega t - \frac{\Phi}{2}\right)$$

at $A$ it is:

$$e_a = E \sin\left(\omega t + \frac{\Phi}{2}\right)$$

The instantaneous potential on each of the $N$ wires at $A$ is:

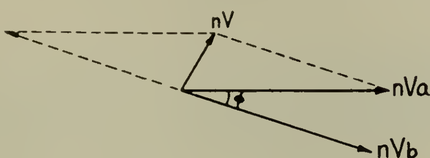
$$v_a = \int_0^h e_a\, dh = e_a h$$

On each of the wires at $B$ it is:

$$v_b = \int_0^h e_b\, dh = e_b h$$

It is the vector difference of the potentials $V_a$ and $V_b$ summed for $N$ wires which causes current to flow in the loop.[8] The vector diagram is shown in Fig. 37.

FIG. 37.




We thus have for the effective instantaneous voltage acting in the serial loop circuit

$$v_r = nv = nEh\left[\sin\left(\omega t + \frac{\Phi}{2}\right) - \sin\left(\omega t - \frac{\Phi}{2}\right)\right] = 2nEh \sin\frac{\Phi}{2}\cos\omega t$$

[8] There are two ways of thinking of the production of driving electromotive in the loop. It can be considered as being induced by the magnetic flux component of the wave, as was done in Part I, or it can be treated as resulting from the phase difference in the electric field at the two sides of the loop as just outlined. It can easily be shown that the value of the e.m.f. acting in the loop is the same whether it is derived on the basis of flux linkages or from the electric forces. The latter method of considering the situation is more instructive in treating the directional characteristics.

The amplitude of this voltage is thus

$$2nEh \sin \frac{\Phi}{2} = 2nEh \sin \left( \frac{\pi l}{\lambda} \cos \alpha \right)$$

For $l$ much less than $\lambda$ as is usually the case

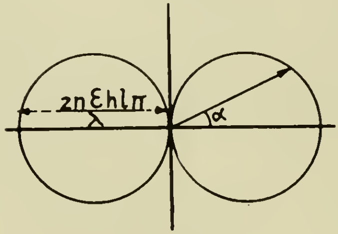
$$\sin \frac{\pi l}{\lambda} \cos \alpha \cong \frac{\pi l}{\lambda} \cos \alpha$$

and amplitude is

$$\frac{2n\,E\,h\,\pi\,l}{\lambda} \cos \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

This is the fundamental equation for the directional characteristics of the loop and gives the two tangent circles of Fig. 38.

Fig. 38.



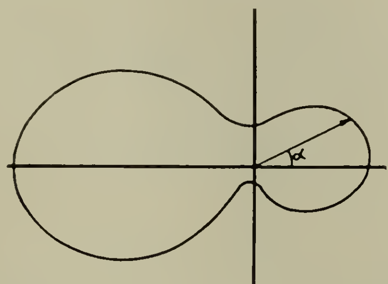

DEVIATION OF THE POLAR CURVE IN PRACTICE FROM THE DOUBLE CIRCLE DERIVED BY THE SIMPLE THEORY.

In practice the directional characteristic of the loop receiver is not so uniform as is indicated by the two tangent circles derived from the simple theory. Its shape has been found to depend in the shape and dimensions of the loop, the manner of winding, proximity to the earth's surface or nearby conductors, the nature of the terrain separating transmitter and receiver and on the arrangement and disposition of the receiving apparatus. A typical curve as obtained by measurement of received signal at different angular positions of the loop may be as shown in Fig. 39. It is seen that there may be a considerable polar dissymmetry with unequal maxima and minima, and although not always as pronounced as is indicated in the figure is nevertheless always present and when augmented by proper design of the apparatus can be readily used for determination of the *absolute* direction or *sense* of a distant transmitter.

It is the purpose of the following discussion to give the reasons for this dissymmetry. The analysis has led to the development of different means of either enhancing or decreasing it so that utility of the loop direction finder is considerably increased.

In general, there are two different types of loops in use: the solenoidal type in which all turns have the same area, and the flat pancake type in which the areas of successive turns decrease toward the centre of the winding. The two types have different directional characteristics, and each will be considered separately.

FIG. 39.




SOLENOIDAL TYPE LOOP.

The type of loop to be considered here is shown in Fig. 40. Its polar characteristic is distorted from the simple circular form, being the combination of three different effects.

1. The displacement current effect.
2. The antenna effect.
3. The shape effect.

1. *The Displacement Current Effect.*—According to the simple theory, when the plane of the loop is at right angles with the direction of wave travel, the electromotive forces developed in wires *a* and *b* are all equal and simultaneously opposite to each other in phase, so that no current flows to the tuning condenser *C*. This conclusion is correct as far as the simple loop effect is concerned, but a certain current does flow to the condenser even at the position $\alpha = 90°$ and this is in part due to what has been here termed the "displacement current effect."

On account of the spacing of the winding there is a phase difference between the voltages developed in successive wires for

FIG. 40.

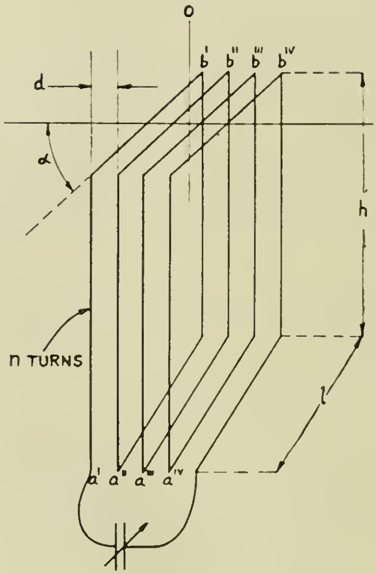
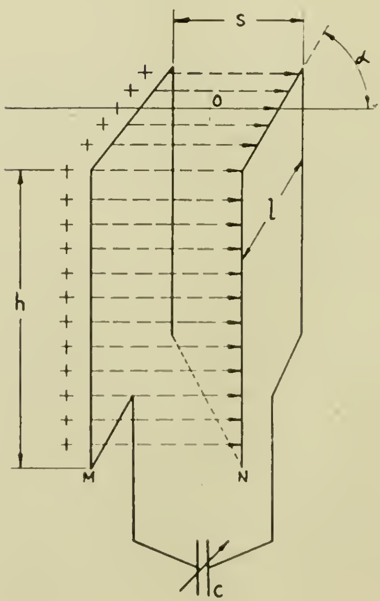



FIG. 41.



all positions except $\alpha = 0°$, and for this reason displacement currents flow across the coil through the series capacities formed by successive convolutions of the winding (see Fig. 41). This current passes out through the tuning condenser $C$ and produces a signal.

In Fig. 41, all the turns have been omitted save the two outer ones. This simplifies the treatment considerably without introducing much error, because what we are really concerned with in any case is the total phase displacement between the first and last turns and the capacity of the ($n$-1) condensers in series formed by the $n$ successive turns.

If, as before, $e = E \sin \omega t$ at centre of loop $O$ then when the plane of the loop is at right angles to the line of wave propagation the instantaneous electric field at $M$ is

$$e_m = E \sin \left(\omega t + \frac{\pi s}{\lambda}\right)$$

At $N$ it is

$$e_n = E \sin \left(\omega t - \frac{\pi s}{\lambda}\right)$$

It is the difference of these two which gives rise to the displacement current between wires.

$$e = e_m - e_n = E\left[\sin\left(\omega t + \frac{\pi s}{\lambda}\right) - \sin\left(\omega t - \frac{\pi s}{\lambda}\right)\right]$$

$$= 2\,E \sin \frac{\pi s}{\lambda} \cos \omega t.$$

The amplitude of this potential difference is thus

$$2\,E \sin \frac{\pi s}{\lambda} \cong \frac{2\,\pi s}{\lambda}\,E \text{ since } \frac{s}{\lambda} \text{ is very small.}$$

This expression holds when the loop is at right angles to the wave, that is, $\alpha = 90°$. For any other angular position it becomes

$$\frac{2\,\pi s}{\lambda}\,E \sin \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In order to get the effect on the detector this must be integrated through the height $h$ so that we get (this is only approximate; more accurate expression is developed below):

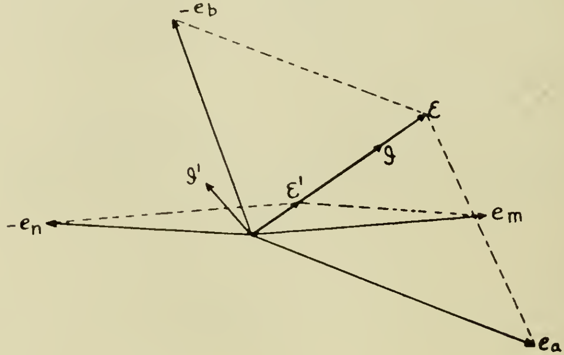
$$\frac{2\,\pi s h}{\lambda}\,E \sin \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

as the expression which must be compared with (1) if it is de-

sired to know the ratio of signals produced by the straight loop effect and the displacement current effect.

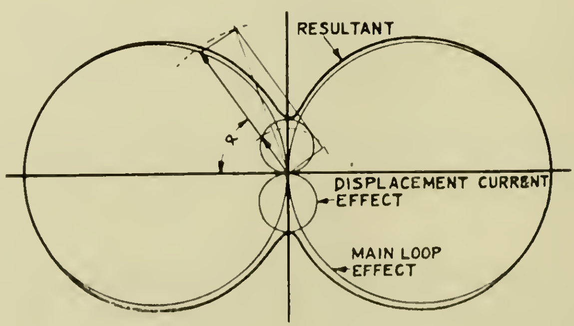
If the displacement current effect is combined with the straight loop effect the result shown in Fig. 43 is obtained. It must be noted in superposing these effects that the two must be added vectorially as at right angles to one another because the *e.m.f.*

FIG. 42.




of the direct loop effect produces current through a tuned circuit and thus in phase with itself while the second effect gives charging current 90° displaced from the voltage. The vector diagram for a given angular coil position is shown in Fig. 42.

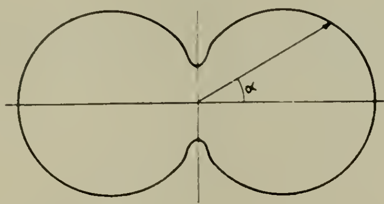
FIG. 43.




There is another displacement current effect besides that first described. It is maximum when the coil is in line with the waves, *i.e.,* in position for maximum signals, and is simply the usual

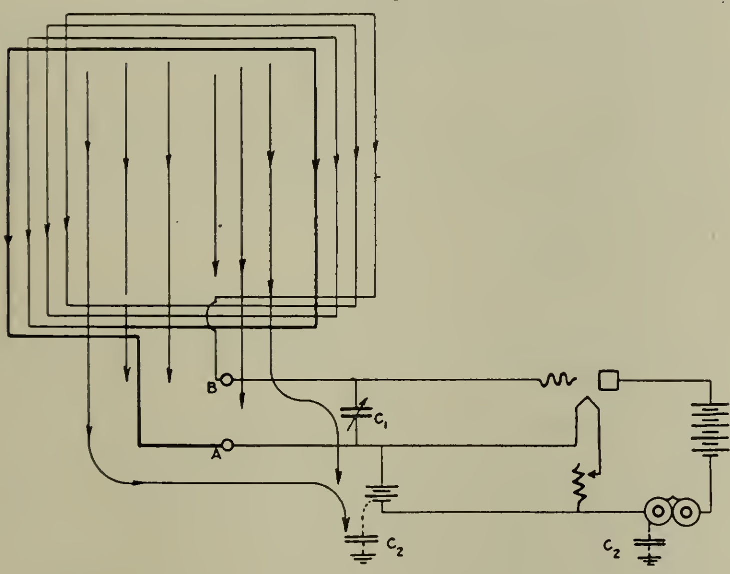
current flowing through the distributed capacity of the coil. It depends on the ratio of inductive reactance to capacity reactance per unit length of the winding, and this, of course, is small (except near the natural frequency of the coil), as is shown by the

FIG. 44.




necessity of having a condenser across the terminals for tuning. It depends, also, of course, on the linear dimensions of the coil, increasing with increase of $l$ and $H$.

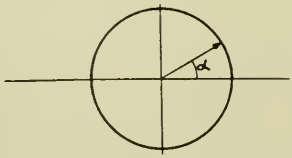
FIG. 45.




The polar curve of the effect would be that shown in Fig. 44, so that if it is taken into consideration its chief effect is to very slightly elongate the major axis of the directional characteristic, and is, therefore, not of great importance.

2. *The Antenna Effect.*—This effect is occasioned by capacity currents to earth from the loop structure acting as a simple antenna and is what produces asymmetry in the polar characteristic. Referring to Fig. 45, it is seen that a certain current flows directly between the loop and ground through the capacity of the filament battery and operator's body; and since the two terminals, *A* and *B*, of the loop have different capacities against ground a voltage is developed between them. The amplitude of this voltage is obvi-

FIG. 46.

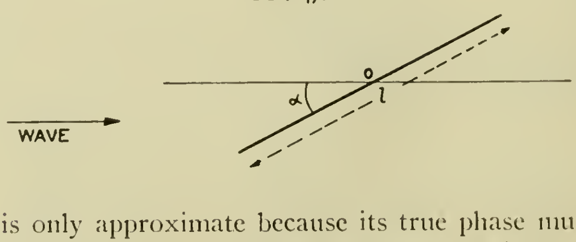



ously independent of the angular position of the loop and hence gives a circular polar characteristic, as in Fig. 46.

The magnitude of the antenna effect is difficult to calculate with any accuracy, but is measured roughly by the height of the antenna (loop).

As regards the detector effect it must be combined with the other voltages in proper phase. It produces essentially a capacity current and hence in time quadrature with the straight loop effect,

FIG. 47.




but this is only approximate because its true phase must be referred to the axis *O* of the loop and hence varies with the angular position. The proper angle to use for the vector combination with the other effects is

$$90^\circ \pm \frac{\pi l}{\lambda} \cos \alpha$$

as can be seen from Fig. 47.

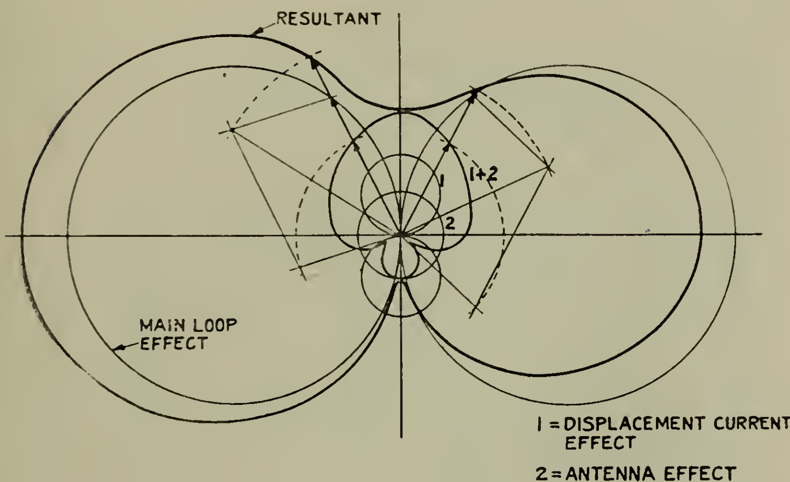
This shift in the phase of the antenna effect produces dis-

tortion in the neighborhood of both maxima and minima of the resultant polar curve where all the effects are combined.

In Fig. 48 is shown the characteristic of a solenoidal type loop as derived by the proper superposition of (1) the straight loop effect, (2) the displacement current effect, and (3) the antenna effect.

3. *The Shape Effect.*—There is an additional distortive effect caused by changes in the ratio of height to length of loop. The nature of this effect is shown in Fig. 49, where the dotted curve is derived for a high, narrow coil, and the solid line for a wide,

FIG. 48.




low coil having half the antenna effect. It is seen that a sharper maximum is to be expected from a tall, narrow coil than for a low, broad one.

The reason for the difference is that the antenna effect for a narrow coil is large and its phase

$$90^\circ \pm \frac{\pi l}{\lambda} \cos \alpha$$

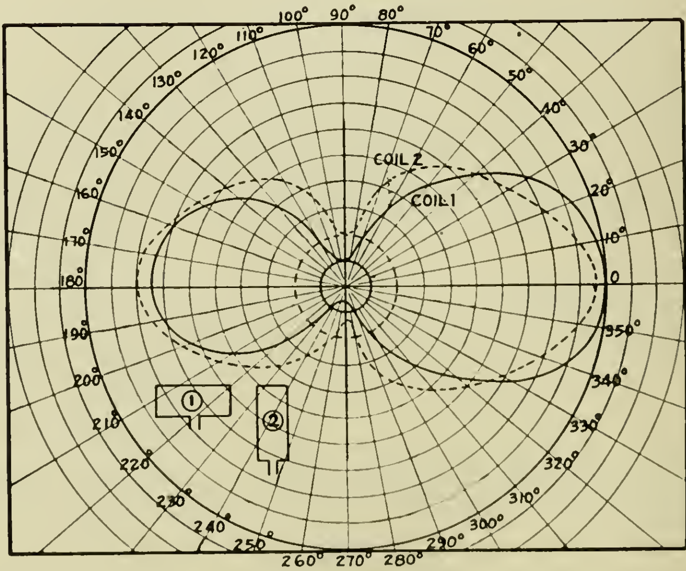
changes only slightly as the coil is turned, while for a broad coil (larger 1) the phase change is greater and since the antenna effect is less (for the same area) the curve is little distorted in the neighborhood of minima but noticeably bulged out toward the maxima.

The shape of the curves of Fig. 49 have been exaggerated for clearness but show the general shape of the total polar characteristic, and have been well checked experimentally.

### IMPROVEMENT OF THE ACCURACY OF THE SOLENOIDAL TYPE LOOP AS DIRECTION FINDER.

In all cases the accuracy of the direction finder depends primarily upon obtaining a sharp minimum in the neighborhood of $\alpha = 90°$. Reference to the above discussion and the Fig. 48 shows that the sharpness of the minimum depends

Fig. 49.




1. On the magnitude of the displacement current effect,
2. On the magnitude of the antenna effect.

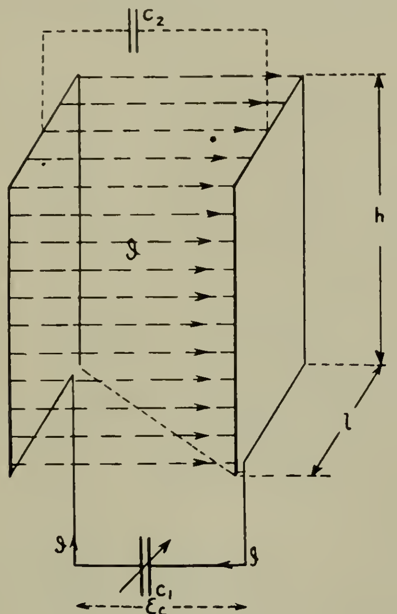
It is necessary to reduce both these effects in order to secure a sharp minimum. Both are affected by the shape of the loop. The displacement current effect for given area is minimum for a *square* loop, because this shape gives shortest possible perimetre and thereby minimum capacity between turns. The antenna effect is less for low coil, *i.e.*, small ratio of $h$ to $l$.

REDUCTION OF THE DISPLACEMENT CURRENT EFFECT.

The displacement current effect can be reduced to a minimum by proper spacing of the wires constituting the winding.

We have,[9] referring to Fig. 50, which is a duplication of Fig. 41, as the voltage across the tuning condenser $C_1$

FIG. 50.




$$E_c = \frac{I}{\omega c}$$

where $I$ = displacement current through the capacity
$C_2$ of the winding.

The voltage producing the current $I$ is, by equation (2)

$$\frac{2\pi s}{\lambda} E$$

Therefore,
$$I = \frac{2\pi s E}{\lambda} \omega \frac{C_1 C_2}{C_1 + C_2}$$

$$c = \frac{2\pi s E}{\lambda} \omega \frac{C_1 C_2}{C_1 + C_2} \cdot \frac{1}{\omega C_1}$$

$$= \frac{2\pi s E}{\lambda} \cdot \frac{C_2}{C_1 + C_2}$$

[9] This treatment is not rigid and is only intended to show approximately what can be accomplished by proper spacing of the winding.

or

$$E_e = K \frac{s\, C_2}{C_1 + C_2}$$

Now $C_2$ is the capacity between parallel wires of length $2(h + l)$ diameter $d$, and separation $s$ and is

$$C_2 = \frac{1}{n-1} \cdot \frac{2\,(h+l)}{2 \log_\epsilon \dfrac{2s}{d(n-1)}} \; cms.$$

Hence

$$E_c = K \frac{s\,(h+l)}{(n-1)\, C_1 \log \dfrac{2s}{d(n-1)} + (h+l)} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

The condition for minimum of this function is

$$\frac{d\,E_c}{ds} = o = \left[(n-1)\, C_1 \log \frac{2\,s}{d\,(n-1)} + (h+l)\right](h+l) - (n-1)\, C_1\, (h+l)$$

or

$$s = \frac{d(n-1)}{2}\, \epsilon^{\,1 - \frac{h+l}{(n-1)\, C_1}}$$

or the spacing between wires $\frac{s}{n-1}$ should be

$$\frac{d}{2}\, \epsilon^{\,1 - \frac{h+l}{(n-1)\, C_1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$\cong 1.4d$ ............ for a many turn winding or where the wave-length is very long so that $C_1$ is large.

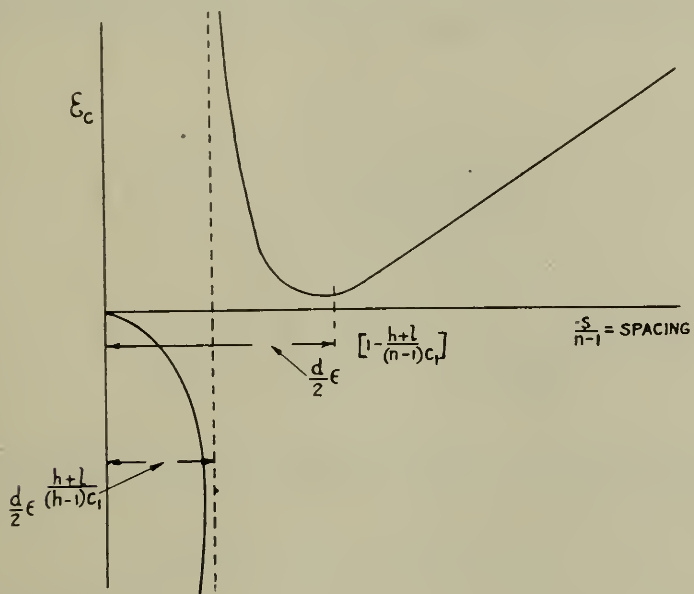
The function (5) is shown graphically in Fig. 51. That is, this figure shows the variation in the magnitude of the displacement current effect with spacing $\frac{s}{n-1}$.

These deductions are of particular value in designing coils for long wave-length work where a large number of turns will be used. For short wave-lengths only a few turns are used and the displacement current is then small in any case, so that usually overall efficiency is more important than the reduction of the displacement currents. For this reason on coils for this class of work using only a few turns the wires will usually be spaced somewhat further apart than the value given by $1.4d$ or (6). As regards long wave-lengths, it was shown in Part I. that the spacing of the wires has not much to do with the efficiency, and hence for such cases a closer spacing may be used, as indicated by $1.4d$, and thus improve the direction finding qualities.

REDUCTION OF THE ANTENNA EFFECT.

As discussed above, the antenna effect is due to capacity currents to ground from the loop through the tuning condenser. In order to eliminate these currents it is necessary that the terminals of the loop, $A$ and $B$ (Fig. 45), have exactly equal capacities against ground. The condition can be partially achieved by raising the filament lighting battery of the receiver well off the ground.

FIG. 51.



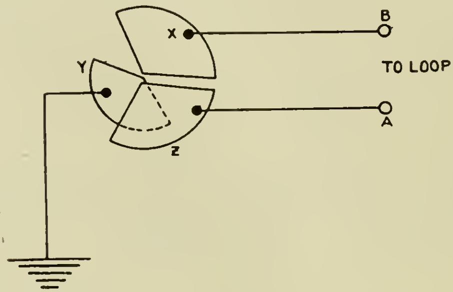

This can never be entirely satisfactory, however, because of the capacity of the operator's body through the telephone (see Fig. 45). If it is desired to obtain complete balance, an auxiliary capacity must be provided from terminal $B$ to ground. The compensator shown in Fig. 52 can be used for this purpose. It consists of three metal plates, $x$, $y$, $z$, two of which, $x$ and $z$, are stationary and connected respectively to the loop terminals $A$ and $B$. The third plate, $y$, is movable and connected to earth. By turning this plate, an exact balance can be obtained for capacity to earth from the loop terminals, and the minimum in the polar curve is thereby sharpened.

Another way in which the antenna effect can be reduced in any loop and the minimum thereby sharpened is by placing a grounded electrostatic shield consisting of several horizontal wires above the loop. The theory would indicate that such arrangement makes for a more symmetrical system electrically and thus excludes, or at least greatly reduces, distortion of the characteristic.

### FLAT PANCAKE LOOP.

The flat pancake type loop acts in a somewhat different way from the solenoidal type. The same general discussion of the

FIG. 52.




simple loop and the shape effect applies to both types, but the antenna effect and the displacement current effect are different.

### DISPLACEMENT CURRENT EFFECT.

The main displacement current effect described above is entirely absent in the pancake loop. This is easily understood by considering the loop in the 90° position, *i.e.*, at right angles to the sending station. In this position there is no phase displacement between the electric fields acting on the several wires and hence no displacement current.

### ANTENNA EFFECT.

The antenna effect is much the same as in the solenoidal type loop, but greater due to the decrease in length of the vertical wires toward the centre of the winding. Instead of being meas-

ured by the height $h$ of the loop as for the solenoid, it is here measured approximately by

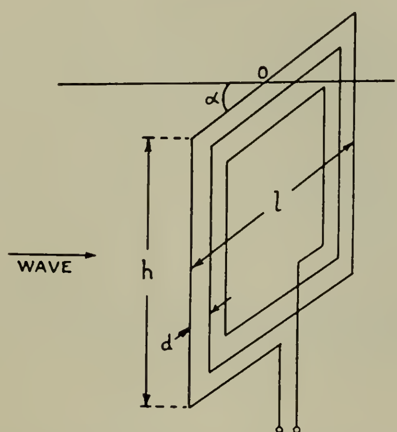
$$h+2nd$$

where $N$ = number of turns
$d$ = spacing between turns.

(See Fig. 53.)

As in the case of the solenoid, the polar amplitude curve of the antenna effect is circular, and in combining its radius vectors with those representing the straight loop effect proper recognition must be taken of the time phase angle between the two. The phase of the antenna effect varies with the azimuth of the loop

FIG. 53.




as for the solenoid and referred to the axis of the loop is approximately

$$90^\circ \pm \frac{\pi l}{\lambda} \cos \alpha$$

STRAIGHT LOOP EFFECT.

Referring to Fig. 53, let

$v$ = Total effective instantaneous potential of straight loop effect in loop for any angular position (azimuth).

$$v = E\left\{h \sin\left(\omega t + \frac{\pi l}{\lambda}\cos\alpha\right) - (h-d)\sin\left(\omega t - \frac{\pi l}{\lambda}\cos\alpha\right)\right.$$

$$\left. + (h-2d)\sin\left(\omega t + \frac{\pi(l-2d)}{\lambda}\cos\alpha\right) - (h-3d)\sin\left(\omega t - \frac{\pi(l-2d)}{\lambda}\cos\alpha\right)\right.$$

$$+ (h-4d)\sin\left(\omega t + \frac{\pi(l-4d)}{\lambda}\cos\alpha\right) - (h-5d)\sin\left(\omega t - \frac{\pi(l-4d)}{\lambda}\cos\alpha\right)$$

$$+ (h-6d)\sin\left(\omega t + \frac{\pi(l-6d)}{\lambda}\cos\alpha\right) - (h-7d)\sin\left(\omega t - \frac{\pi(l-6d)}{\lambda}\cos\alpha\right)$$

$$+ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$+ (h-2(n-1)d)\sin\left(\omega t + \frac{\pi(l-{}^2(n-1)d)}{\lambda}\right)\cos\alpha$$

$$\left. - (h-(2n-1)d)\sin\left(\frac{\omega t - \pi(l-{}^2(n-1)d)}{\lambda}\cos\alpha\right)\right\}$$

Let

$$\frac{\pi\cos\alpha}{\lambda} = k$$

$$\omega t = \theta$$

$$v = \left\{\begin{array}{l} h\sin\theta\cos kl + h\cos\theta\sin kl - (h-d)\sin\theta\cos kl + (h-d)\cos\theta\sin kl \\ + (h-2d)\sin\theta\cos k\,(l-{}^2d) + (h-2d)\cos\theta\sin k\,(l-{}^2d) - (h-3d)\sin\theta\cos \\ \quad k\,(l-{}^2d) + (h-3d)\cos\theta\sin k(l-{}^2d) \\ + (h-4d)\sin\theta\cos k(l-4d) + (h-4d)\cos\theta\sin k\,(l-4d) - (h-5d)\sin\theta \\ \quad \cos k\,(l-4d) + (h-5d)\cos\theta\sin k(l-4d) \\ + \ldots\ldots\ldots\ldots\ldots\ldots \\ + [h-2\,(n-1)\,d]\sin\theta\cos k\,(l-{}^2\,(n-1)d) + [h-2\,(n-1)\,d]\cos\theta\sin k \\ \quad (l-{}^2(n-1)d) \\ - [h-(2b-1)d]\sin\theta\cos k(l-{}^2\,(n-1)d) + [h-(2\,n-1)\,d]\cos\theta\sin k \\ \quad (l-{}^2(n-1)d) \end{array}\right\}$$

As approximation can be used the first two terms of the cos and sin expansions into series by Maclaurin's theorem.

$$\sin x = x - \frac{x^3}{L^3}$$

$$\cos x = 1 - \frac{x^3}{L^2}$$

Now

$\frac{l}{\lambda}$ is never $> 0.01$

$$\therefore \quad \cos kl = \cos\frac{\pi l}{\lambda}\cos\alpha \cong 1$$

$$\sin kl \cong kl = \frac{\pi l}{\lambda}\cos\alpha$$

Hence

$$v\,E\left\{\begin{array}{l} h\sin\theta + hkl\cos\theta - (h-d)\sin\theta + (h-d)\,kl\cos\theta \\ + (h-2d)\sin\theta + (h-2d)\,k(l-{}^2d)\cos\theta - (h-3d)\sin\theta + (h-3d)\,k \\ \quad (l-{}^2d)\cos\theta \\ + (h-4d)\sin\theta + (h-4d)\,k\,(l-4d)\cos\theta - (h-5d)\sin\theta + (h-5d)\,k \\ \quad (l-4d)\cos\theta \\ + \ldots\ldots\ldots\ldots\ldots\ldots \\ + [h-2\,(n-1)d]\sin\theta + [h-2\,(n-1)\,d]\,k\,(l-{}^2\,(n-1)d)\cos\theta \\ \quad - [h-(2n-1)d]\sin\theta + [h-(2n-1)d]\,k(l-{}^2(n-1)d)\cos\theta \end{array}\right\}$$

$$= E\left\{\begin{array}{l}\Big[h-(h-d)+(h-2d)-(h-3d)+(h-4d)-(h-5d)+\ldots\ldots\ldots\ldots \\ \qquad +(h-2(n-1)d)-(h-(2n-1)d)\Big]\sin\theta \\ \Big[k+hl+(h-d)l+(h-2d)(l-2d)+(h-3d)(l-2d)+(h-4d)(l-4d) \\ \quad +(h-5d)(l-4d) \\ \quad +\ldots\ldots\ldots+[h-2(n-1)d]\,[l-2(n-1)d]+[h-(2n-1)d]\,[l-2 \\ \qquad (n-1)d]\Big]\cos\theta\end{array}\right\}$$

$$= E\left\{\begin{array}{l}d\,\big[1-2+3-4+5-\ldots\ldots\ldots-2(n-1)+(2n-1)\big]\sin\theta \\ +k\,\big[hl+hl-dl+hl-2dl-2hd+4d^2+hl-3dl-2hd+6d^2+hl-4dl-4dh+ \\ \quad 16d^2+hl-5dl-4dh+20d^2+\ldots\ldots\ldots\ldots \\ +hl-2(n-1)dl-2(n-1)dh+4(n-1)^2d^2+hl-(2n-1)dl-2(n-1)dh+2 \\ \qquad (2n-1)(n-1)d^2\big]\cos\theta\end{array}\right\}$$

$$= E\left\{\begin{array}{l}nd\sin\theta+k\,\big[2nhl-dl(1+2+3+4+5+\ldots\ldots\ldots 2(n-1)+(2n-1)) \\ \quad -2hd(1+1+2+2+\ldots\ldots(n-1)+(n-1)) \\ \quad +2d^2(2+3+8+10+\ldots\ldots 2(n-1)^2+(2n-1)(n-1))\big]\cos\theta\end{array}\right\}$$

$$= E\left\{\begin{array}{l}nd\sin\theta+k\,\big[2nhl-n(2n-1)dl-2n(n-1)dh \\ \quad +2d^2(2+3+8+10+\ldots\ldots 2(n-1)^2+(2n-1)(n-1))\big]\cos\theta\end{array}\right\} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$v = nE\left\{\sqrt{d^2+k^2\Big[2hl-(2n-1)dl-2(n-1)dh+\frac{2d^2}{n}(2+3+8+10+\ldots\ldots\ldots 2(n-1)^2+(2n-1)(n-1)\Big]^2}\right\}\sin(\theta+\gamma) \qquad \ldots\ldots\ldots\ldots (8)$$

where

$$\gamma = \tan^{-1}\frac{k\,\Big[2h-(2n-1)dl-2(n-1)dh+\frac{2d^2}{n}(2+3+8+10+\ldots\ldots 2(n-1)^2(+(2n-1)(n-1)\Big]}{d} \qquad \ldots\ldots\ldots\ldots (9)$$

Equations (7), (8) and (9) show that the straight loop effect of the pancake may be thought of as made up of two parts to be added vertorially at 90°. One of these,

$$n\,d\,E$$

is independent of angular position and therefore circular; the other,

$$k\Big[2hl-(2n-1)dl-2(n-1)dh+2\frac{d^2}{n}(2+3+8+10+\ldots 2(n-1)^2+(2n-1)(n-1))\Big]$$

varies according to $k$, *i.e.*, the cosine of the angle, and hence appears as two tangent circles. The phase $\gamma$ of the resultant of these referred to the loop axis varies also with Cos $\alpha$. The

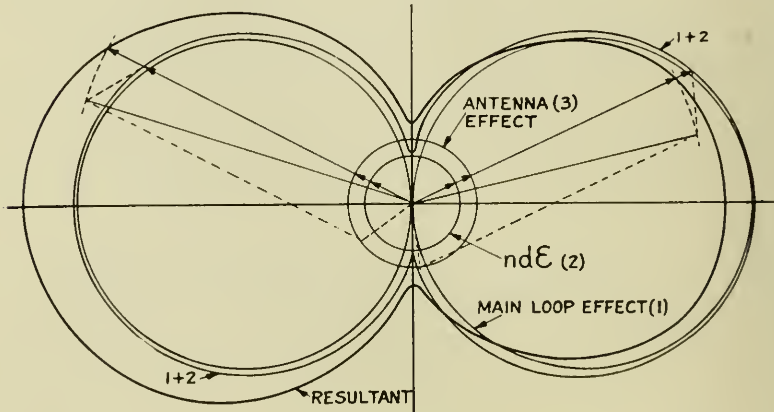
angle to be used, therefore, in combining the antenna and straight loop effect is

$$T = \gamma \pm \left(90^\circ + \frac{\pi l}{\lambda}\cos\alpha\right)$$

$$Tan^{-1} = 90^\circ \pm \frac{\pi \cos \alpha}{\lambda}\left[2hl-(2n-1)dl-2(n-1)dh+\frac{2d^2}{n}(2+3+8\ldots\ldots)+l\right]$$

It is seen from this expression that the angle $T$ at which the antenna effect and the direct loop effect must be combined changes with different angular coil positions. This is a very significant circumstance. It gives rise to distortion of the polar curve which is particularly noticeable in the neighborhood of maxima. In the pancake loop it is not essentially the cause of a broader mini-

Fig. 54.




mum on one side of the curve than on the other. This is due to a combination of the antenna effect with the second displacement current effect mentioned under the solenoid loop, which latter has its maximum value when $\alpha = 0$.

Fig. 54 is drawn to show the various effects in a pancake loop and their resultant. The shape effect is not shown, but, as has been explained, tends principally to elongate the curve along the major axis. The second displacement current effect is also omitted for simplicity, thus giving symmetrical minima.

### FACTORS AFFECTING DISTORTION AND SHARPNESS OF MINIMUM.

The sharpness of the minimum can be increased by decreasing the term $n$ [see equation (7)]; that is, by decreasing the radial

depth of the winding. It can be further increased by decreasing the antenna effect; that is, by decreasing the wire spacing or by any of the means described for the solenoid loop. This also reduces dissymmetry in the characteristic.

When the dissymmetry is desirable as for finding *absolute* direction, the pancake type winding should always be used and the antenna effect increased by any means possible. A rather wider spacing of the wires is, therefore, desirable in this case than would ordinarily be used on a solenoid loop.

Increasing the spacing must not be carried to extreme, however, since it seriously impairs the accuracy of the coil as direction finder by broadening the minimum.

It is, in fact, true and a point of practical interest that the pancake loop usually never has as sharp minimum as the solenoidal type, because, even for equal antenna effects in the two cases, the displacement current effect in the solenoid, measured by

$$\frac{2 \pi s E}{\lambda}$$

is much smaller than the equivalent " winding " pitch effect of the pancake which depends on

$$n\, d\, E$$

In regard to this statement it should be pointed out that the theoretical characteristics for the two types of loops (Figs. 48, 49 and 54) are not drawn to scale nor with the exact distortion angles, so that they cannot be compared with each other. Tendencies only are indicated.

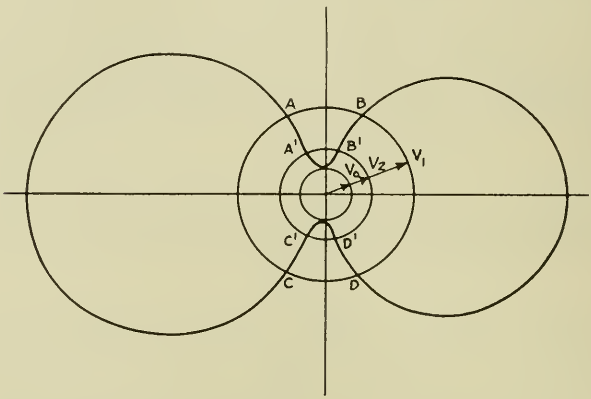
### EFFECT OF RECEIVER SENSITIVENESS NECESSITY FOR RADIO FREQUENCY AMPLIFICATION.

The accuracy of the direction finder and the speed with which settings can be made depend on the sharpness of the minimum points in the directional polar characteristic. Some of the factors that effect this have just been discussed, but there is in addition to these another very important one, namely, the sensitiveness of the detecting apparatus.

If the sensitiveness is made very great, it is often difficult to find an absolute zero as the loop is rotated. It will sometimes only be possible to find a more or less restricted region of minimum signal strength, the reasons for which are evident from the

figures and the discussion above. Nevertheless, it is generally desirable to have the detection sensitiveness as great as possible for the following reason: If the polar curve is as shown in Fig. 55 and the sensitiveness of the detecting apparatus is such that it just responds to the potentials of value $V_1$, and voltages less than this cannot be detected, then as the loop is rotated zero response will be obtained through the regions $AB$ and $CD$. If, however, the detector sensitiveness is greater so that smaller voltages down to value $V_2$ can be detected the zero regions are narrowed down to $A'B'$ and $C'D'$ and the apparatus becomes more accurate. By

Fig. 55.




further increasing the sensitiveness still greater accuracy is obtained as the zero regions are further narrowed and, in the case shown, an increase in sensitiveness to correspond to the potential $V_0$ would give a single point or position where there would be zero response.

It is very desirable to produce this condition, but to do so requires extremely sensitive detecting apparatus as well as a very sharp antenna (loop) characteristic. If the zero regions are wider than a few degrees so that they cannot be accurately and quickly bisected experimentally, the average of the four readings, $A$, $B$, $C$, $D$, where the signal becomes inaudible must be taken as an indication of the true minimum, and although this requires time, it has, nevertheless, been found to give good accuracy provided the regions of silence do not exceed about 30°. With the

uncompensated loop midpoints of the regions *AB* and *CD* are not 180° apart, as has already been shown, and this makes it necessary to average all four readings as just described.

On account of the exponential relation between current passed and applied potential, all the usual radio detectors respond much more effectively to large impressed voltages, that is strong signals, than they do to weak ones. In other words, the ordinary detector (including the vacuum tube) is insensitive to weak signals, and since it is always in the region of weak signals that the directional setting is made there is a great loss of accuracy. No amount of audio frequency amplification will overcome the difficulty because the audio frequency amplification cannot be brought into play until the detector is "triggered off." It is for these reasons that it has been found necessary to amplify the radio frequency energy before passing it to the detector by means of a multistage radio frequency amplifier.

## PART III.

### EXPERIMENTAL CHECKING OF RESULTS AND PRACTICAL FORMS OF APPARATUS DEVELOPED.

Space does not permit a full account of the large number of experiments that have been made to check the conclusions arrived at from the above theoretical considerations, nor of those made for the purpose of amplifying the theory and gathering certain additional data necessary for the actual design of apparatus. Neither is it possible here to fully cover descriptions of the various types of loops, loop connections, and associated apparatus that have been developed for special uses. Suffice it to say that continuous experimental effort has been carried on for more than a year following and paralleling the theoretical deductions and not only has the theory been substantiated in every respect but several important applications suggested by the theory have been reduced to practice in a very gratifying way. The present section is divided into three parts:

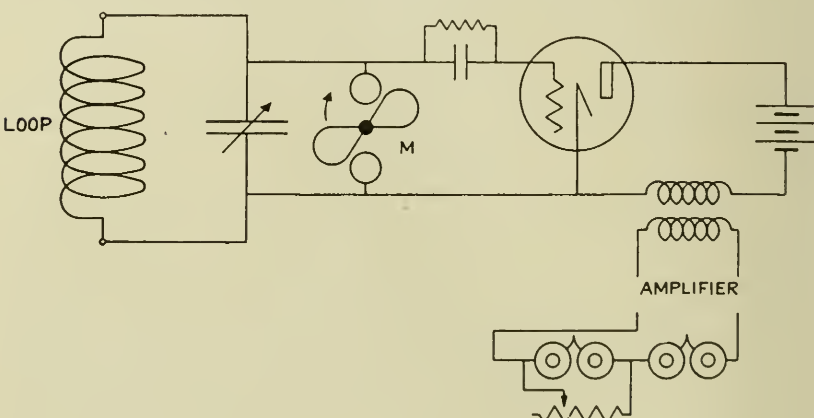
1. Examples and method of checking design data of Part I.
2. Experimental verification of Directional Characteristics and improvement of same.
3. Special developments and uses.

I.

METHODS USED IN VERIFYING DESIGN DATA OF PART I.

In order to check the results of Part I, giving data on the design of loops from the standpoint of high receiving efficiency, a number of measurements were made of received signal strength in actual undamped wave transmissions. For this purpose a vacuum tube transmitter with antenna was set up 1/5 mile distant from the loop receiver to be tested and the signal at the receiving end measured on various loops at different wave-lengths by the shunted telephone method. The current in the transmitting antenna was adjusted to the same value at all wave-lengths by means of a variable resistance placed in the antenna circuit.

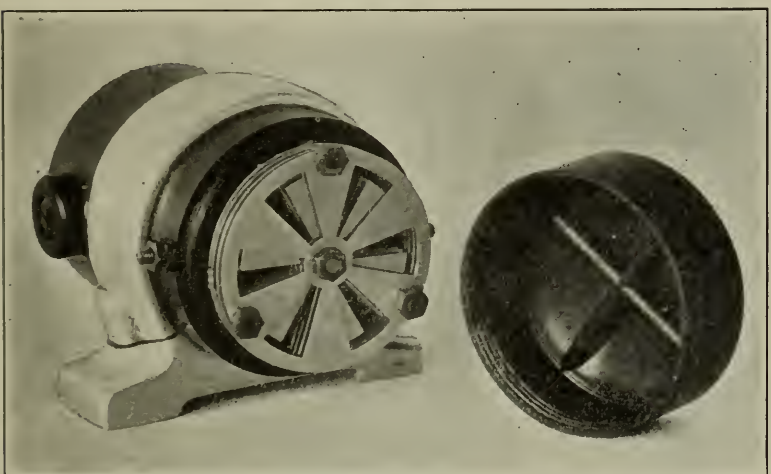
Fig. 56.




The arrangement of receiving apparatus in most of the experiments was that shown in Fig. 56. An ordinary non-oscillating detector tube with a multistage amplifier is connected to the tuned loop circuit in the usual way across the variable condenser. In order to get audible response from the incoming undamped oscillations the modulator $M$ is connected across the main tuning condenser. This modulator consists of a set of stationary sectored metal discs and insulated therefrom another set of similarly sectored movable discs fastened to the shaft of a small electric motor. The device thus constitutes a condenser whose

capacity varies continuously from its minimum through its maximum values as the motor rotates. The number of sectors and the speed of rotation is so chosen that the variation of capacity through the extreme values occurs at an audible rate of, say, 300 or 400 times a second. The tuning condenser is adjusted somewhere near to the value of capacity required to tune to the incoming signals; then as the modulating condenser revolves the system is alternately brought into and out of tune at an audible rate by it and the gushes of energy fed to the detector each time resonance is reached cause a signal in the telephones of corre-

FIG. 57.



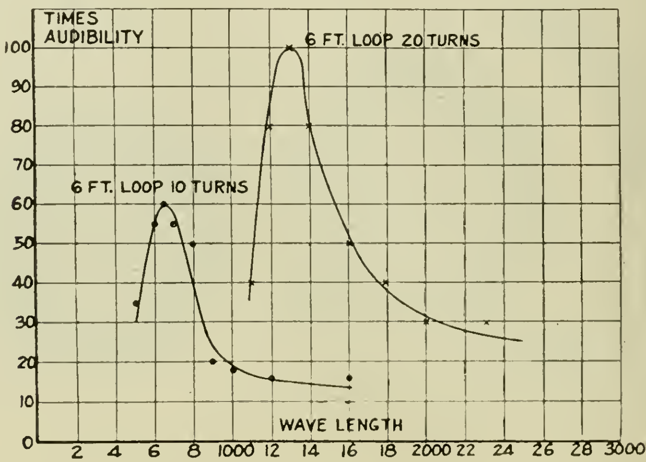
sponding pitch. A photograph of the modulator built for this purpose is shown in Fig. 57. With this method the strength of signal depends only on the amplitude of the signal oscillation, a condition which is not true when reception is carried on by the heterodyne or endodyne methods.

Two of the curves obtained on 6 ft. square 10 and 20 turn loops are shown in Fig. 58. Audibilities are plotted against wavelength. Referring to Fig. 28 of Part I., where the derived characteristics for these loops are shown, it is seen that the present curves check those obtained by calculation very well, and since this agreement has been found to exist for a number of cases investigated in the same way it must be concluded that the design

data of Part I. are satisfactorily representative of the performance of the loops which it is intended to cover.

A word should be said further with regard to reception on the heterodyne or endodyne principles. In the former case where a separate local oscillator is used at the receiver to produce beats with the incoming signal oscillation the functioning of the apparatus does not involve any essentially different points other than those already considered. The larger the voltage impressed on the detector by the incoming oscillation the stronger will be the signal, other adjustments of local oscillation being properly made in every case. In the case of endodyne reception where the receiving circuits are themselves oscillating, conditions are ordi-

FIG. 58.

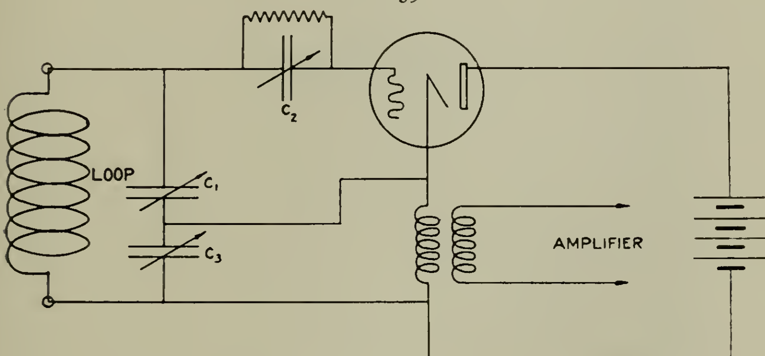



narily somewhat different. The impedance of the receiving circuit to the locally produced oscillation is zero and is equal to the resistance of the circuit for incoming oscillations having the same frequency as those produced locally. It is necessary, however, in order to secure audible beats, to adjust the local frequency to a different value than that being received so that the impedance presented to the latter is not equal to the resistance of the circuit but has a higher value depending upon the amount of detuning. The percentage detuning obviously varies with the wave-length and with the note it is desired to produce in the telephones, so that the energy collected does not ordinarily follow exactly the same

variation with wave-length as with the separate heterodyne or with the non-oscillating receiver. At long waves a considerable loss in efficiency results from the large amount of mistuning necessary to get audible beat frequencies. The overall efficiency also depends upon the way in which the receiving circuit is oscillating, upon the ratio of the strength of its oscillations to those of the incoming wave, so that the matter is very complex and, as just stated, the best signals for a given loop may not necessarily come exactly at the wave-lengths indicated in the charts; but their location depends a good deal on the particular adjustment used.

To illustrate the characteristic reception obtained by the endodyne method several curves were taken on different loops using

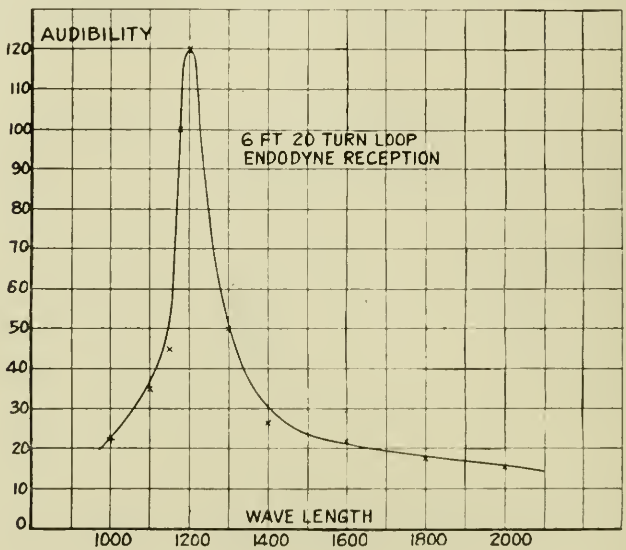
Fig. 59.




the receiver shown in Fig. 59. One of these cuves is shown in Fig. 60 for the 6 ft. 20 turn loop mentioned above. The beat pitch was held constant for all wave-lengths and was rather high (about 800 cycles per second) corresponding closely to the natural vibration rate of the telephone receiver diaphragms. Condenser $C_3$ was kept fixed and the adjustments were made each time with the tuning condenser $C_1$ and the grid condenser $C_2$. The curve shows that the best reception for the loop, under the conditions of the test, comes at about 1200 metres instead of 1300 metres as in the case of non-oscillating reception, and that the shape of the curve is different. The latter circumstance, and in particular the rapid falling off for wave-lengths longer than the optimum value, is due in large part to the mistuning required to produce the beat note.

It is possible to considerably increase the efficiency of this type of receiver and to more nearly match its performance with the predicted curves by coupling the oscillating detector inductively with the loop circuit so that the entire system has two free electrical periodicities separated by an amount corresponding to the desired beat frequency. One of these periodicities can be made equal to that of the incoming oscillations, while the other corresponds to the local beating frequency. In this way the impedance

FIG. 60.




of the circuit to the incoming oscillation is equal to its resistance and the voltage produced at the detector by this oscillation, therefore, follows such variations as have already been delineated for the non-oscillating or separate heterodyne cases. A third tuned circuit coupled to the ordinary loop receiving circuit may be used for the same purpose and with similar results.[10]

[10] No correction was made in above experiments for change in radiation resistance at transmitting antenna with wave-lengths. The antenna was very low, however, and radiation resistance therefore practically constant for the wave-lengths.

## II.

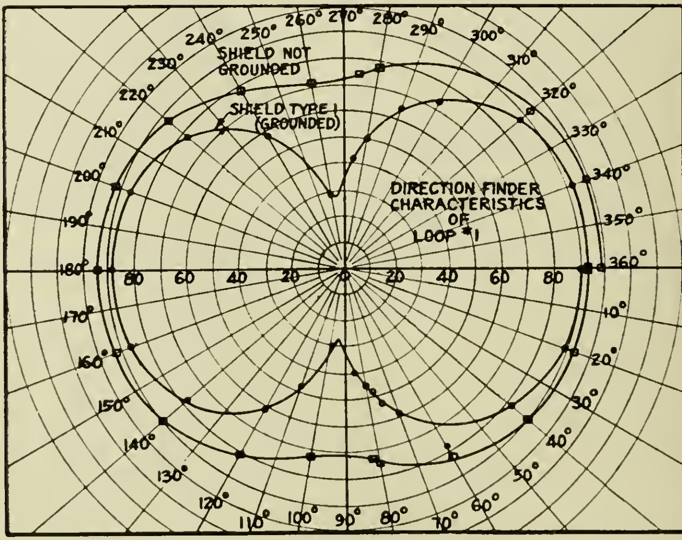
### EXPERIMENTAL CHECKING OF DIRECTIONAL CHARACTERISTICS AND IMPROVEMENT OF SAME.

Several methods have been used for investigating experimentally the directional characteristics of loop antennas. One of these which has given dependable results is the following: A 10 watt vacuum tube transmitter is connected to a small antenna of any of the orthodox types and furnishes a source of electromagnetic waves. In some of the tests which are about to be described a current of 1.0 amp. was obtained in a single wire inverted "L" antenna 20 ft. high by 100 ft. long. The loop whose directional qualities were to be studied was set up, in this case, 1.6 miles distant. It was connected to a tuning condenser and oscillating vacuum tube detector, and the response of the latter was then amplified by four stages of audio frequency amplification. The output of the last tube of the amplifier was used to actuate a thermoelement connected to a galvanometer. Thus, the energy picked up by the loop, as it was rotated through different azimuthal angles, could be recorded by visual indications and with a very little practice extremely accurate polar curve characteristics could be obtained. In the actual set-up the thermoelement was one having 197 ohms heater resistance, and 12 ohms couple resistance, and operating in a vacuum. It was fed from the low side of a 30,000 ohm to 200 ohm step down repeater coil. This repeater coil with the particular values of impedance stated was used in order to match the amplifier tube internal output impedance on the high side, and the thermo-couple impedance on the low side and thus get maximum output. The galvanometer used took the form of a single pivot Paul micrometer giving full scale deflection for 360 micro-amps. Considerable trouble was at first experienced, due to howling of the four stage amplifier, but this was finally overcome by careful wiring and proper disposition of the apparatus. A large number of polar curve characteristics has been taken, using this set-up, of various loops under nearly every conceivable condition and some of the conclusions arrived at are summarized below.

Of particular interest is the study that was made of the possibility of sharpening the minimum and increasing the symmetry of the characteristic by using overhead electrostatic shields as

proposed in the theoretical discussion of Part II above. Twenty-seven different curves were taken in this investigation, covering different designs of shields and arranged differently with respect to their distance from the loop.[11] A few of these curves are reproduced herewith to indicate the actual practical improvement obtainable in the loop direction finder through the use of correctly arranged shield superstructure. In Fig. 61 are shown the

Fig. 61.



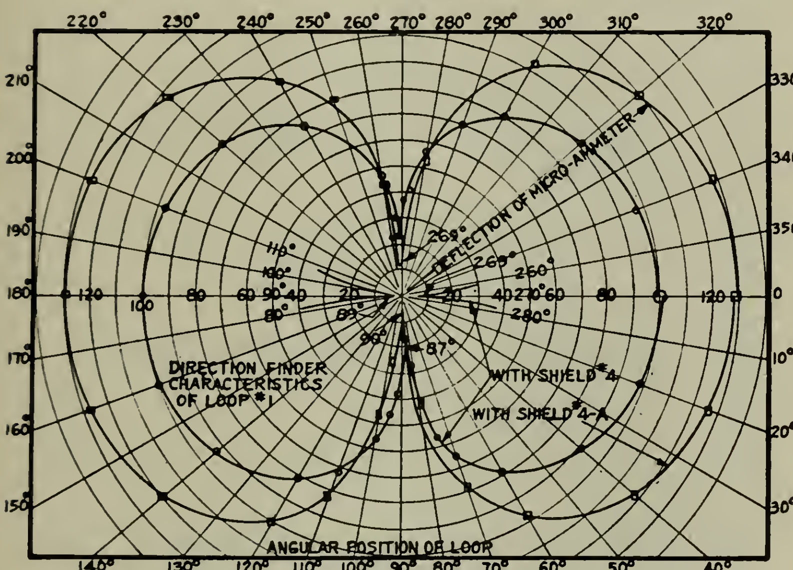

characteristics of a 5 ft. square solenoid type loop having 6 turns of No. 18 wire spaced 3/8″ apart, both with and without a shield. The shield in this case took the form of a 5 ft. flat pancake wound loop, 3″ between turns, mounted on top of the vertical receiving loop with one of its diagonals coincident with the top of the vertical loop and its plane parallel to the earth. The shield was, of course, grounded. It is seen that a much sharper minimum is obtained with the shield than without it.[12]

[11] The data of these tests were taken by 2nd Lieutenant Leon T. Wilson, Signal Corps.

[12] It should be noted that all of these curves would be elongated along the major axis were it not that strong signals are not amplified as much as weak ones in the apparatus used due to the curvature of the amplifier characteristic.

The curves of Fig. 62 were taken on the same 5 ft. 6 turn loop with two other type shields. These shields consisted of a harp of 24 No. 16 parallel wires 5¾ ft. long spaced ¾″ apart and held in horizontal plane ¾″ above the loop. The odd numbered wires were all joined together at their middle and the even numbered wires were similarly connected. When all of the wires were used this shield was called No. 4, and when half the wires were used it was called No. 4-A. The loop was set up on a farm near Lincroft, New Jersey. The complete curves were taken on different days.

FIG. 62.

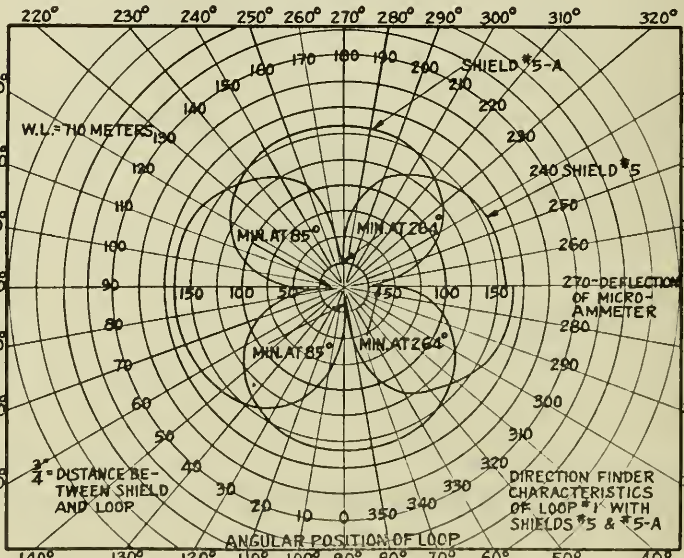



The curve for shield No. 4 was taken with 650 metres and No. 4-A with 710 metres wave-length. The small No. 4 curve and the No. 4-A curve were taken on the same morning and are comparable. It is seen from the curves that shield No. 4 has slightly better shielding qualities than shield No. 4-A, and that the minima are practically 180° apart. The minima checked with the actual direction of the station, being exactly at right angles thereto. The curves show a difference in the sharpness of the minima obtained with shield No. 4 on the two days. This is probably due to the different wave-lengths used and different weather condi-

tions, both of which factors influence the magnitude of the antenna effect.

Still two other shields were used, which were built exactly like No. 4 and No. 4-A, except that there was a total of thirty-five 6 foot long wires spaced 1″ apart. The shields were designated No. 5 and No. 5-A for the 1″ and 2″ spacing, respectively, which was provided in the same way as on shields No. 4 and No. 4-A. The curves for these two shields are shown in Fig. 63. They show that little is to be gained by using the one inch spacing instead of the two inch spacing, a result which checks the performance of shields No. 4 and No. 4-A.

Fig. 63.




Figs. 64 and 65 give an idea of the undesirable effect on the minima caused by extra capacity to ground furnished by the operators wearing the head telephones.

Fig. 66 shows the curves obtained with different distances between the loop and shield. The best distance for shield No. 5 appears to be about ¾″.

Fig. 67 shows a curve taken very near to and partly under a tree. The minima are broadened somewhat and there is a slight distortion.

Fig. 64.

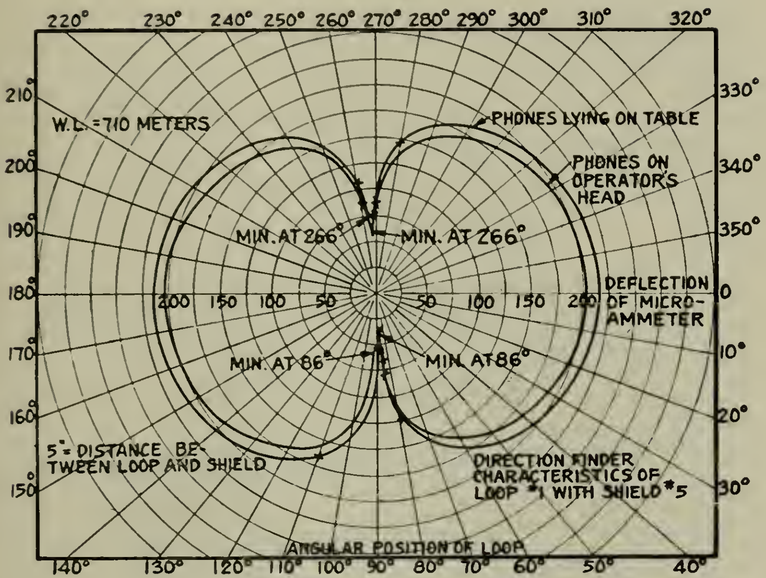

220° 230° 240° 250° 260° 270° 280° 290° 300° 310° 320°
210° 200° 190° 180° 170° 160° 150°
330° 340° 350° 0 10° 20° 30°
140° 130° 120° 110° 100° 90° 80° 70° 60° 50° 40°
W.L. =710 METERS
PHONES LYING ON TABLE
PHONES ON OPERATOR'S HEAD
MIN. AT 266°
MIN. AT 266°
200 150 100 50 50 100 150 200
DEFLECTION OF MICRO-AMMETER
MIN. AT 86°
MIN. AT 86°
5" = DISTANCE BE-TWEEN LOOP AND SHIELD
DIRECTION FINDER CHARACTERISTICS OF LOOP #1 WITH SHIELD #5
ANGULAR POSITION OF LOOP

Fig. 65.

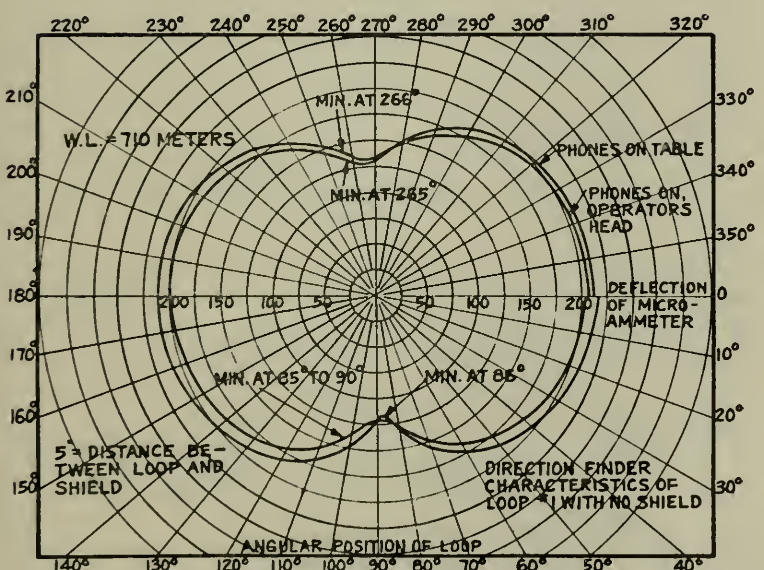

220° 230° 240° 250° 260° 270° 280° 290° 300° 310° 320°
210° 200° 190° 180° 170° 160° 150°
330° 340° 350° 0 10° 20° 30°
140° 130° 120° 110° 100° 90° 80° 70° 60° 50° 40°
MIN. AT 266°
W.L. = 710 METERS
PHONES ON TABLE
MIN. AT 265°
PHONES ON, OPERATORS HEAD
200 150 100 50 50 100 150 200
DEFLECTION OF MICRO-AMMETER
MIN. AT 85° TO 90°
MIN. AT 86°
5" = DISTANCE BE-TWEEN LOOP AND SHIELD
DIRECTION FINDER CHARACTERISTICS OF LOOP #1 WITH NO SHIELD
ANGULAR POSITION OF LOOP

Fig. 66.

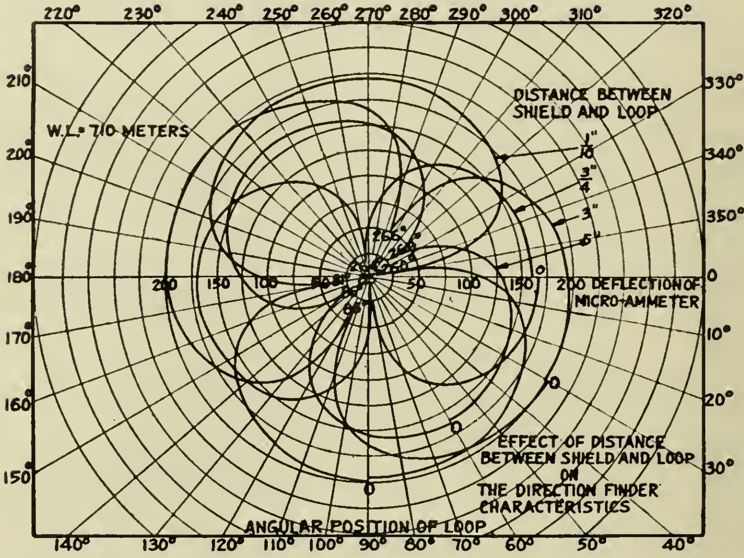

W.L.=710 METERS
DISTANCE BETWEEN SHIELD AND LOOP
1/10"
3/4"
3"
5"
DEFLECTION OF MICRO-AMMETER
EFFECT OF DISTANCE BETWEEN SHIELD AND LOOP ON THE DIRECTION FINDER CHARACTERISTICS
ANGULAR POSITION OF LOOP

Fig. 67.

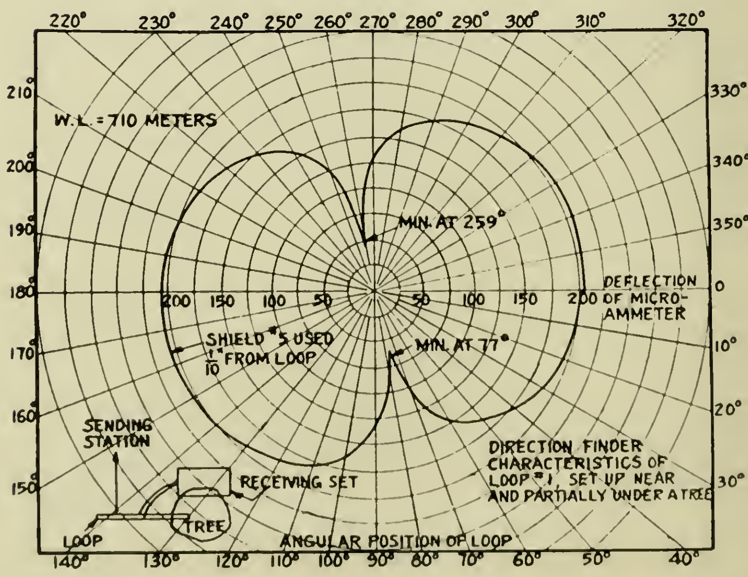
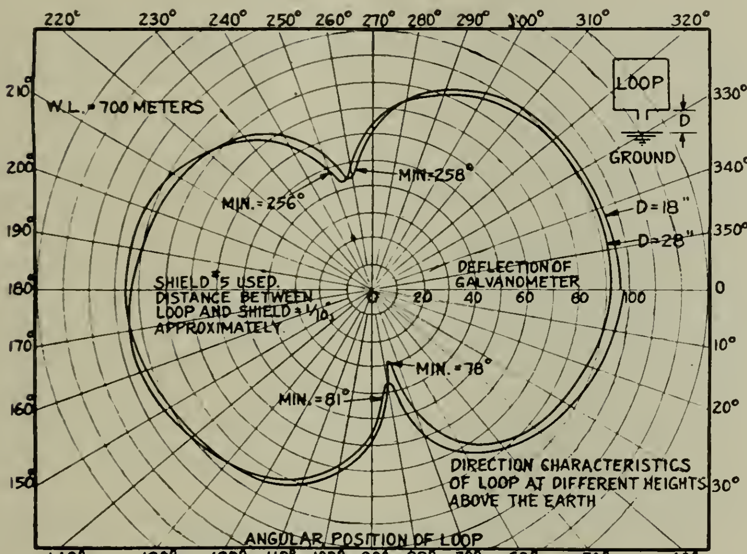

W.L.=710 METERS
MIN. AT 259°
DEFLECTION OF MICRO-AMMETER
SHIELD #5 USED 1/10" FROM LOOP
MIN. AT 77°
SENDING STATION
RECEIVING SET
TREE
LOOP
DIRECTION FINDER CHARACTERISTICS OF LOOP #1, SET UP NEAR AND PARTIALLY UNDER A TREE
ANGULAR POSITION OF LOOP

Fig. 68 is a partial record of the effect of changing the distance of the loop above the earth. It is seen that even the relatively small change from a height of 18″ to one of 28″ causes noticeable improvement in symmetry and sharpness of minima. It has been found that still better results may be had at a height of 4 or 5 ft., and when the entire apparatus was placed in a wooden barn 20 ft. from the ground extremely accurate settings could be made.

Fig. 68.




The general conclusions that were derived from all of these experiments with particular reference to the various factors affecting the accuracy (that is, the sharpness and position of the minima) of the direction finder are as follows:

(*a*) *Sharpness and Symmetry of Minima.*—With a single simple loop the minima are sometimes sharp and sometimes very broad and are not generally equal nor 180° apart.

(*b*) *Effect of Electrostatic Shield.*—The use of an electrostatic shield above the loop is in general very advantageous in improving the sharpness and symmetry of the minima. It does not noticeably reduce the strength of received signal.

(*c*) *Pancake vs. Solenoid Loops.*—The minima of the pancake type loop are generally broader than those of the solenoid type. There is a greater difference in the amplitudes of the two oppositely directly maxima for the pancake than for the solenoid.

(*d*) *Grounding Any Part of the Receiving Apparatus.*—Either grounding parts of the receiving apparatus (for example, grounding the filament battery of an amplifier to prevent its "howling") or placing parts of the apparatus close to the earth broadens the minima and therefore decreases the accuracy of the loop (partial grounding of the set through the telephone receivers on the operator's head has a small though noticeable effect). The grounded shield was found to partially correct this loss in accuracy but not completely. Therefore, the receiving apparatus and batteries should be kept at least 2 or 3 feet off the ground.

(*e*) *Proximity of Loop to Earth.*—The proximity of the loop to the earth produces a broadening and a slight distortion of the minima when the shield is used. To obtain good results the lower edge of the loop should be at least 4 feet off the ground.

(*f*) *Effect of Nearby Metal Objects.*—A Ford truck was placed very close to the loop (with a shield) and was found to have negligible effect, even with the frame of the truck grounded. On the other hand, the loop and shield when used in a building with numerous radiators of a heating system in it, gave minima which were about 4° off from being 180° apart. The loop should, therefore, not be set up near extended masses of metal or near wires.

(*g*) *Effect of Trees.*—Scattered trees 30 or 40 feet from the loop have negligible effect on the direction finder. A tree which is but a few feet away causes a slight distortion of the minima. Many large trees 30 or 40 feet from the loop and between the loop and the transmitting station appreciably reduce the strength of signal.

(*h*) *Effect of Atmospherics.*—Certain kinds of atmospherics are considerably reduced by the grounded shield.

(*i*) *Polarity of Loop.*—Under ordinary conditions the solenoidal loop with or without the shield gives one minimum sharper than the other. Reversing the leads from the loop to the receiving set reverses the sharp minimum.

(*j*) *The Distance of the Shield Above the Loop.*—The best distance of the shield above the loop was found to be about 3/4" to 1 1/2" for the apparatus of ordinary dimensions.

(*k*) *Use of Shield When the Complete Direction Finding Apparatus is High Off the Ground.*—Although the shield is very effective in sharpening the minimum when the loop is 3 or 4 feet off the ground, and the receiving apparatus 2 or 3 feet off the ground, it loses its value when all the apparatus is 15 or 20 feet from the ground. Under these conditions the loop has good directional qualities without a shield.

## III.

### PRACTICAL DEVELOPMENTS AND USES.

While it is not essentially the purpose of this report to describe in detail the several practical developments of radio direction finding apparatus that have been made nor its uses, it is, nevertheless, interesting, in connection with the work described above, to mention certain special applications that have been made of the principles involved which are believed to be novel.

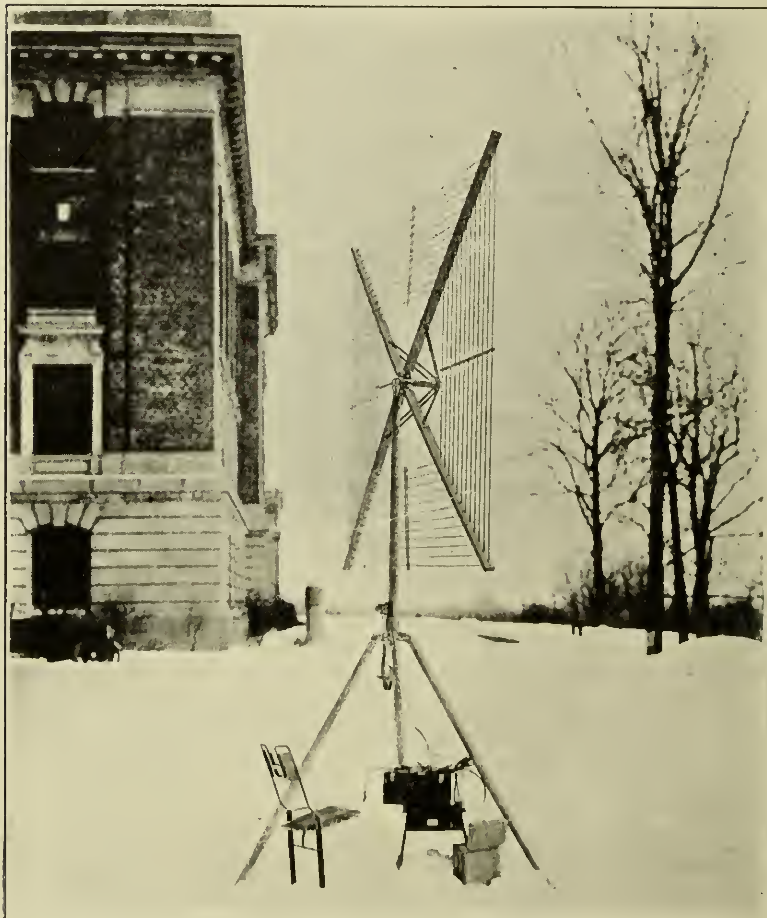
One of these is the construction and use of a single loop for finding *absolute* direction, a result obtained by properly augmenting the antenna effect and the phase of same so as to produce distortion in the polar curve characteristic with unequal maxima and minima. A photograph of a portable field apparatus which accomplishes this in a satisfactory way while retaining sufficiently sharp minima for accuracy in directional settings is shown in Fig. 69. Absolute direction or sense is obtained by a rough setting of the loop in a position for maximum signal strength and then either rotating the loop through 180° or reversing the leads to the detector. The directional sense of the sending station is then determined by noting whether the first or the second arrangement gives the louder signals. The exact line is fixed, as usual, by right angle settings.

A second novel method of using the loop followed the discovery that at certain heights, different from a certain value, above ground a loop placed with its plane horizontal, that is parallel to the earth, acted as a very good receiver and was practically non-directional. Such an arrangement is useful for many purposes, such, for example, as intercept work.

A combination of vertical loop, giving the two-leaved characteristic, with a horizontal loop, giving a circular characteristic, may be used to get absolute direction, and by suitable switching

arrangements the horizontal loop may be used alternately as a shield for improving the sharpness of minimum and for giving antenna effect, as just described, and getting absolute direction.

FIG. 69.



A model has been standardized by the Signal Corps using a carefully designed solenoidal type loop with an electrostatic shield for very accurate direction finding work.

It was found (December, 1917) that when the plane of a loop of certain design was placed at a certain angle with the earth

and at a certain height no radio signals could be received from certain directions. While the uses to which this important discovery have been put cannot be disclosed at the present time, it may be stated that they are concerned with a very great improvement in the reliability of radio communication. Other arrangements of specially constructed loops and associated apparatus have also been developed and are being improved with the same end in view.

In concluding this paper, it should be stated that a great deal of the work that has been done on the loop direction finder itself has been paralleled by investigations and development of multistage amplifiers, necessity for the use of which has been pointed out above. A seven tube amplifier comprising three stages of radio frequency amplification, a detector tube, and then three stages of audio frequency amplification, has been developed and standardized by the Signal Corps for direction finding work. This instrument is more sensitive, has fewer adjustments, is less noisy, lighter and more compact, and altogether a more generally satisfactory instrument in operation than any similar apparatus having the same order of amplification that has been developed by either the British, the French, or the Germans. The total overall power amplification obtained on weak signals is of the order of $10^{14}$ times. A novel feature of the amplifier is the use of iron in the radio frequency transformers which couple the radio stages. Incident to the development of this and similar amplifiers a very thorough study was made of the characteristics of iron at radio frequencies, and data were collected giving the permeability and losses in steel that was found suitable for use in these transformers. The iron that has been used in this work is 0.0015″ thick, lacquered with a special enamel to the thickness of 0.002″. It is a low carbon steel containing no appreciable amount of silicon.

Using the seven stage amplifier just mentioned and a loop small enough to be easily accommodated in an ordinary size room, it has been possible to receive signals from all of the high power European stations.

The loop has been used for direction finding on both damped and undamped waves. In the latter case, as has been described above, either a separate local heterodyne may be used at the receiver, or the receiving circuits themselves can be made to oscillate. Using a separate heterodyne, care must be taken to prevent

any direct action of the local oscillation on the loop circuit itself, because in such cases the directional setting will be incorrect. This is because the signal produced is due to the combination of the signal wave and the heterodyne wave, and almost any setting can be obtained, depending upon the amplitude of the local wave and upon the direction from which it intercepts the loop. When using a separate heterodyne, the local oscillation must be introduced into the circuits through a small localized coupling with no leakage of the loop system.

Finally, adaptation of the loop receiver has been made to the airplane in another special form of apparatus for direction finding and the same principles and data given above have been applied in the design of the loops for this purpose.

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**Corrosion in Lenses.** (*The British Journal of Photography*, vol. lxvi, No. 3088, p. 389, July 11, 1919.)—If lens users would acquire a little elementary knowledge concerning the nature and properties of glass, their instruments would stand a much better chance of keeping in good condition than they do at present. It should be known that what we call "optical" glass is made in a great variety of qualities, each of which is capable of taking its place in one or other of the many kinds of lenses. Some are as hard and impermeable as the glass we use for windows and tableware, while others are soft enough to be easily scratched or even dented, while injudicious polishing will quickly dim the exquisite surface upon the perfection of which so much depends. This is especially the case in some of the earlier anastigmats in which very soft and easily corroded glasses were used because others were not available. It is perhaps news to many people to learn that some glasses are so susceptible to damp that a single drop of water left upon the surface for a few hours will leave an ineradicable mark, while the presence of a film of condensed moisture will give rise to a general corrosion, which in mild cases shows in prismatic colors like those of a soap-bubble, and in severe ones as a yellow stain accompanied by a distinct depolishing of the surface. Unfortunately, there is no cure for this evil, for even the maker of the lens cannot repolish it to the same accuracy of figure that it originally possessed. Forewarned is forearmed, and knowing what is likely to occur the prudent man does not allow his lenses to stand about exposed to the atmosphere, but keeps them in tightly-closed cases when they are not actually in use. Failing a case, which also protects the brasswork, a well-fitting cap at the back as well as the front is an excellent protection.

# THE LOW VISIBILITY PHASE OF PROTECTIVE COLORATION.*

BY

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A CAREFUL analysis of protective coloration as a means of defense against attack by submarines leads to the conclusion that the subject may, from the standpoint of fundamental method, be divided into two quite distinct and different parts. The object to be accomplished is the same in both cases, that is, to prevent the destruction by submarine attack of the protectively colored craft. This object may be attained by either of the two general methods. The first, which will be called "low visibility" coloration, involves the application of paint (together with certain structural modifications that may be necessary), in such a way that the craft treated so nearly matches the background against which it must be viewed as to be invisible or less visible to an observer on the submarine. The second, which will be called "deceptive" coloration, involves the application of paint or the modification of structural details, or both, in such a way as to deceive the submarine's observer in his estimate of the nature of the craft, her range, course or speed, thus preventing the submarine from ever reaching an advantageous firing position, or, in case it is reached, to so confuse the submarine's commander in his calculations that the torpedo will not be discharged in such a direction as to secure an effective hit. This latter method aims not at preventing an attack from being made, but at preventing the attack from being successful.

It is quite evident that the first method will be most effective when the distance between the submarine and the protectively colored craft is relatively great, let us say, in excess of 5000 yards. Likewise, it is reasonable to conclude that the second method will be found most effective at relatively close range, under 5000 yards. This conclusion follows from consideration of the fact that "deceptive" coloration depends for the efficiency of its operation

* Communicated by Dr. C. E. K. Mees. Communication No. 80 from the Research Laboratory of the Eastman Kodak Company.

upon the visibility of the shape and color of various contrasting areas produced by the application of paint alone or in conjunction with certain modifications of structural details. Since " low visibility " coloration and " deceptive " coloration differ in the means employed for the accomplishment of the desired result, it will be necessary to treat each separately.

When the work on this subject was taken up a survey of the field showed that at that time no method for the numerical specification of visibility, or instrument for its quantitative measurement, was available. The first step, therefore, was the working out, from the theoretical standpoint, of the fundamental laws upon which the quantitative evaluation of visibility could be based. Following this an instrument, operating upon the proper principle as indicated by the theoretical equations, and suitable either for the measurement of visibility values of small models under known conditions of illumination and background or of actual boats at sea, was designed and built. This having been accomplished, it remained to apply the method and instrument to the determination of the best color for low visibility under any specified weather condition.

In this paper it is proposed to present some of the data resulting from the application of the method and instrument to the measurement of visibility. Since the theory of visibility and of the instrument constructed for its measurement have been treated in detail in a previous paper,[1] those phases of the subject will be only briefly considered at this time, thus permitting the placing of greater emphasis upon the practical results obtained. It will be necessary, however, in order to understand the data and their interpretation, to consider briefly the fundamental laws governing the visibility of objects and the method adopted for the numerical specification of its value.

In general, it may be said that non-luminous objects are visible by virtue of the light reflected from them. However, any particular object in the field of vision becomes visible as such only by contrast with its surroundings—that is, when the light emanating from that object (either by reflection or emission) differs in some respect from the light flux which enters the eye from the projected space immediately surrounding that object. The sensation caused by the incidence of radiant energy, which we call

[1] Paper read at meeting of American Physical Society, April, 1919.

light, upon the retina of the eye may be said to consist of two factors, brightness and color, the former being dependent upon the intensity and the latter upon the quality of the incident radiation. This second factor of the sensation may also be said to consist of two parts, hue and purity or saturation. Hue refers to the position, in the spectrum, of the dominant wave length, and saturation expresses the proximity of the color to monochromatism. It is evident, therefore, that a sensation due to the impingement of radiant energy upon the retina may vary in three respects, that is, with respect to brightness, hue, and saturation. A contrast in the visual field resulting in the visibility of an object may be due, therefore, to brightness contrast, to hue contrast, or to saturation contrast; or to a combination of any two or of all three of these factors.

### NOMENCLATURE AND DEFINITIONS.

The intensity factor of the sensation resulting from the incidence of radiant energy upon the retina is expressed in terms of brightness. The brightness, $B$, of an element of luminous surface from any point of view may be expressed in terms of the luminous intensity per unit area of that surface projected on a plane perpendicular to the line of sight. When expressed in this manner it is measured in candles per unit area of the projected area. Brightness may be expressed also, and perhaps more logically, in terms of the specific luminous radiation of an ideal perfectly diffusing surface, that is, a surface obeying Lambert's law. The brightness unit in this case is the Lambert which is defined as equal to the brightness of an ideal surface radiating or reflecting one lumen per square centimetre. In practice, this unit is too large for convenience and hence the millilambert of .001 lambert is used. An ideal, perfectly diffusing surface emitting one lumen per square foot will have a brightness of 1.076 millilamberts. Measurements of brightness are made by means of a suitable form of photometre calibrated to read directly in the desired brightness units. The brightness of a surface depends upon two factors, the illumination of that surface and its reflecting power.

The illumination, $E$, of a surface at any point is the luminous flux density on the surface at that point, or the flux per unit of intercepting area. "Luminous flux," $F$, is the rate of flow of radiant energy evaluated with reference to the visual sensation.

and is expressed in lumens, the lumen being defined as equal to the flux emitted in a unit solid angle (steradian) by a point source of unit candle power. The *c. g. s.* unit of illumination is the phot, which is defined as one lumen per square centimetre. The practical unit in most common use, however, is the foot candle which is defined as one lumen per square foot, and which is equal to 1/076 milliphots. For a uniformly illuminated surface,

$$E = \frac{F}{S}, \quad S \text{ being the area.}$$

Illumination is measured by a special type of photometer, usually referred to as a lumeter or illummometer, this being calibrated to read directly in some suitable illumination units.

The coefficient of reflection or total reflecting power of a surface is defined as the ratio of the total reflected luminous flux to the total incident luminous flux. In most practical work this value is not of great importance, the value desired being that of the reflecting power of the surface measured under certain specified conditions, such as the angle of incidence of the flux and the position from which the surface is viewed. The term "reflection factor," *R*, is used to indicate this particular value and is defined as the ratio of the reflected to the incident flux. Reflection from a surface may be either specular, diffuse, or a mixture of the two. In the case of pure specular reflection all of the incident flux is reflected in such a way that the angle of reflection is equal to the angle of incidence; while in the case of completely diffuse reflection the reflected flux is equal in all directions, regardless of the angle of incidence, the distribution being in accord with Lambert's cosine law. Very few cases of pure specular or diffuse reflection are found in practice, there being generally a superposition of the two. The reflection factor is measured by the use of the reflectometer, a photometer of special design, care being taken that conditions of illumination and angle of view are such as to give correct values for application in the particular case under consideration. This value is purely numeric and is usually expressed as a percentage value. If, with a specified condition of illumination, the reflection factor, *R*, and the brightness, *B*, of the surface are measured from the same position, then $B = E \cdot R$, and hence the value of *E* may be determined; or in any case where two of these factors are known the third can be computed.

The quality factor of the luminous flux is that property which depends upon the spectral distribution of that flux, color being

defined as the subjective evaluation as expressed in terms of hue and purity or saturation. Hue is that property of color which depends upon the variation in the sensation due to the variation of the wave length of the luminous flux, while saturation expresses the proximity of the color to a condition of monochromatism. Monochromatic spectral light has a saturation of 100 per cent., while pure white light has a saturation of zero. White, therefore, is a limiting color, having no hue and zero saturation. In practice it has been found convenient in many cases to express the saturation factor in the inverse order, that is, as impurity rather than purity. The term used in such expression is called the "per cent. white," for which the symbol $I$ is used. Thus a color for which $I = 100$ per cent. is equivalent to zero saturation, and if $I = 0$ per cent., saturation is 100 per cent.

It has been demonstrated experimentally that any color can be matched by the mixture, in the proper proportions, of white light with monochromatic spectral light of the proper wave length. In this way a direct measurement of the fundamental sensation properties of a color may be made. The hue is specified by the wave length of a monochromatic light used (wave length of the dominant hue). The saturation is specified either as the purity (per cent. hue) or as the impurity (per cent. white), the former value being obtained from the ratio of the intensity of the monochromatic to the total intensity (monochromatic plus white) of the mixture, while the latter value (per cent. white) is given by the ratio of the intensity of the white to the total intensity of the mixture. These values are pure numerics. The usual unit used in expressing the wave length of light is the millimicron, which is equal to .0000001 centimetre and is designated by the symbol $\mu\mu$.

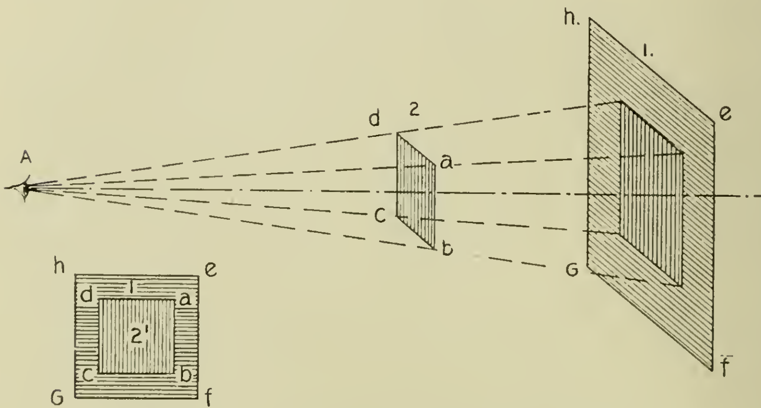
In the foregoing paragraphs have been defined the various terms that will be used in the following discussion of the subject of visibility. These are summarized briefly in the following table for convenience of reference:

| Symbol. | Quantity. | Unit. |
|---|---|---|
| $F$ | Luminous Flux | Lumen |
| $E$ | Illumination | Foot Candle |
| $B$ | Brightness | Lambert |
| $R$ | Reflection Factor | Per cent. |
| $H$ | Hue | Wave length ($\mu\mu$) |
| S | Saturation | |
| | Purity | Per cent. Hue |
| | Impurity | Per cent. White |

THEORETICAL ANALYSIS OF THE LOW VISIBILITY PROBLEM.

For the purposes of the theoretical treatment of this problem it will be necessary to make certain simplifying hypotheses. Begin first with the problem of the determination of the visibility of an object uniform in color and brightness viewed against a background also of uniform color and brightness. In Fig. 1 this case is shown in perspective, 1 being the background, 2 the object, and $A$ the eye or viewpoint. The visual field will appear as shown in the lower left hand drawing of Fig. 1, 2 representing the object (rectangle *abcd*) and 1, the background (rectangle *efgh*).

FIG. 1.




A diagrammatic illustration of the relation of object to background.

The terms used in the discussion and the symbols employed are as indicated previously, except that a subscript number or letter attached to a given symbol indicates that the term applies to the object or surface designated by that number or letter. Thus $E_1$ is the symbol used for the illumination on the surface 1, the background.

Assume for the moment that the object and background are illuminated by light of the same quality and also that this quality be specified as white, which is defined as light from the noon sun on a clear day or its spectral equivalent. Now, the visibility, $V$, of the object as seen against this background is dependent upon the total contrast existing between the two. This total contrast

is made up of the three factors: (1) Brightness contrast, $C_b$; (2) Hue contrast, $C_h$, and (3) Saturation contrast, $C_s$. These three factors of the total contrast may be evaluated as follows:

$$C_b = f\,(B_1, B_2)$$
$$C_h = f\,(H_1, H_2)$$
$$C_s = f\,(S_1, S_2)$$

The total visibility may then be expressed in the general form,

$$V = f\,(C_b, C_h, C_s).$$

The laws governing the reaction of the retina to the various brightness stimuli are so well established that it is comparatively easy to evaluate the term $C_b = f\,(B_1, B_2)$ directly in terms of visibility, to make quantitative measurements of visibility as such, and to correlate such determinations made under widely different conditions. Unfortunately, the other terms, $C_h$ and $C_s$, cannot be so readily evaluated. This is due to the lack of knowledge concerning the fundamental reactions of the retina to these stimuli. However, it is possible by a direct method of measurement to determine the total visibility of an object against a given background. Such a value includes in a single term the visibility due to all three kinds of contrast. Since the part of total visibility due to brightness contrast may be determined independently, a means is thus available of evaluating that part of visibility due to the combined effect of hue and saturation contrast. Since hue and saturation are the two factors of quality, the part of total visibility due to hue and saturation may for convenience be designated as quality contrast, $C_q$. It should be borne in mind, however, that this term includes two independent variables, both of which must be considered in any evaluation of visibility due to quality contrast. It is entirely possible that the visibility due to $C_h$ and $C_s$ could be evaluated separately, but this would require a large amount of fundamental research, which it will not be advisable or necessary to go into at this time.

The visibility resulting from brightness contrast is directly proportional to the subjective contrast and hence, for an eye adapted to a fixed brightness level, to the ratio of the two brightnesses $B_1$ and $B_2$. Therefore, we may write:

$$V_b = f\left(\frac{B_1}{B_2}\right) \qquad (1)$$

Now, suppose that to both $B_1$ and $B_2$ some brightness, $B_v$, is added and that $B_v$ is of such magnitude relative to $B_1$ and $B_2$ that,

$$\frac{B_1 + B_v}{B_2 + B_v} = k \tag{2}$$

Where,

$$k = 1 + \frac{\triangle B}{B_1} \tag{3}$$

$\triangle B$ is the least perceptible difference in brightness when the eye is adapted to a field brightness of $B_1$.

The superposed brightness, $B_v$, will be referred to as "veiling glare," and the magnitude of $B_v$ required to satisfy the equation above may be taken as a direct measure of the visibility of an object under fixed conditions. It is evident, however, that the value of $B_v$ required by the equation will depend not only upon the ratio of $B_1$ to $B_2$ but also upon the absolute values of those terms. An evaluation of visibility dependent upon the ratio of $B_1$ to $B_2$ and independent of their magnitude may be obtained by writing

$$V_b = \frac{B_v}{B_1} \tag{4}$$

It is evident that a variation in value of any one of the four terms, $E_1$, $E_2$, $R_1$ and $R_2$, will cause a corresponding change in the value of $V_b$. Visibility may be evaluated, therefore, as a function of any one of these four terms as a variable and the remaining three as constants. It is entirely possible to evaluate each of these functions, but a consideration of the problem to which the theory is later to be applied shows that this is not necessary and that a different method of evaluation is more directly applicable.

As will be shown later, the sky forms the background in most of the cases to be considered, and it is impossible in general to treat the sky as a surface. It is not possible, nor is it necessary, to determine independently the values of the reflection factor and illumination in dealing with this sky background. However, its brightness can be measured easily, and from the standpoint of brightness the sky may therefore be regarded and treated as a surface. The variables $E_1$ and $R_1$ are therefore eliminated from this problem, being replaced by a single term, $B_1$. This leaves for consideration the three variables, $E_2$, $R_2$ and $B_1$, for each of which as a variable an evaluation of $V_b$ may be formulated. Again,

considering conditions in nature, it will be seen that $E_2$ and $B_1$ are not in general independent variables but more or less dependent one upon the other. It is desirable, therefore, to combine these two into a single term, as a function of which visibility may be expressed. This combination of $B_1$ and $E_2$ is best accomplished by taking the ratio of the former to the latter. This ratio is a complete specification of the lighting conditions at any instant, and is therefore in the practical problem of an object illuminated by natural light a complete specification of the weather conditions at a given time. This term will be referred to as the "weather coefficient," $W$, its evaluation in terms of the other quantities being expressed by the equation,

$$W = \frac{B_1}{E_2} \tag{5}$$

The variables to be considered are, therefore, $R_2$ and $W$, and the necessary evaluations of visibility are of the form, $V_b = f(R_2)$, $W =$ a constant; and $V_b = f\ (W)$, $R_2 =$ a constant. The first equation when properly formulated will make possible the computation of the variation in visibility due to a variation in the value of the reflection factor, for any specified value of the weather coefficient; the second equation will give the variation in visibility with the value of the weather coefficient for any object of definite reflection power.

Before proceeding with the formulation of these visibility functions it is desirable, for the sake of clearness, to summarize briefly the terms thus far defined which must be used in the subsequent development of the theory.

$B_1$ = Brightness of background.
$R_2$ = Reflection of factor of object.
$E_2$ = Illumination of object.
$R_2$ = Reflection of factor of object.
$B_v$ = Brightness of veiling glare which when superposed over object and background will reduce the contrast to a just imperceptible value.
$V_b$ = Brightness visibility.
$W$ = Weather coefficient.
$k$ = Contrast of the eye.

The evaluation of visibility due to brightness contrast in terms of $W$ and $R_2$ leads to the following general expression:

$$V_b = \left(\frac{1}{W} \cdot R_2 \cdot \frac{c}{1-c}\right) - \frac{1}{1-c} \tag{6}$$

Where $c$ is a constant depending for its value upon whether $B_1$ is greater or less than $B_2$.

If,

$$\frac{B_1}{B_2} > k, \qquad c = k$$

or if,

$$\frac{B_1}{B_2} < k, \qquad c = \frac{I}{k}$$

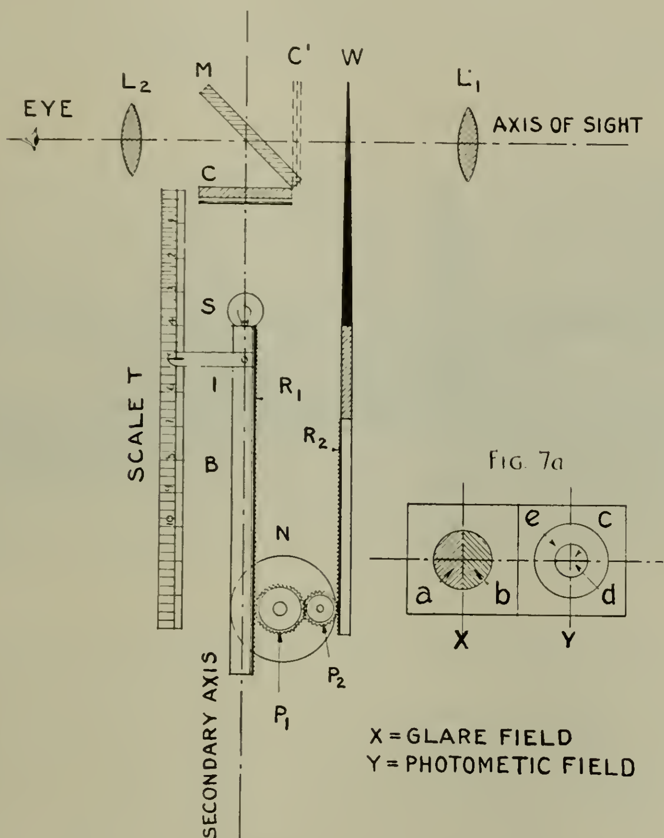
It will be noted from the form of the expression that visibility as a function of $W$ ($R_2$ = a constant) will be represented by a rectangular hyperbola and as a function of $R_2$ ($W$ = a constant) by a straight line.

### THE VISIBILITY METRE.

The general principles upon which the specifications of visibility must be based have been outlined in the section dealing with the theory of the subject. It will be remembered that visibility may be specified in terms of the brightness of a veiling glare, $B_v$, and the brightness of the background, $B_1$, against which the object is viewed. This veiling glare was defined as that brightness which, when superposed upon the visual field composed of an object and its background, will reduce the apparent contrast between object and background to the limit of visibility. It will be remembered that the discussion referred to dealt with the evaluation of the visibility due to brightness contrast, $V_b$. Now suppose that in addition to a brightness contrast, a contrast in either hue or saturation also exists. The amount of veiling glare required to reduce the total contrast to a just perceptible value will in general be greater than in case the color contrast was not present. It is entirely logical, therefore, to apply the same general method for the evaluation of total visibility, that is, the superposition over the object and background of a veiling glare of sufficient brightness to reduce the total contrast to zero. The distinction between the terms $V_b$ and $V$, the total visibility, should, however, be borne in mind. The total visibility in any case, whether that visibility be due either to brightness, hue or saturation contrast, or to any combination of these terms, is evaluated in terms of the equivalent brightness contrast which would produce the same degree of visibility. The validity of such a method is strongly supported by the fact that loss of visibility in nature is almost entirely due to the presence of a veiling glare which is quite con-

stant in quality, its color being approximately white, but variable in intensity. This natural veiling glare arising from the presence of diffusing material in the foreground space produces a lowering of the visibility value regardless of whether the initial visibility is due to brightness, hue or saturation contrast.

FIG. 2.

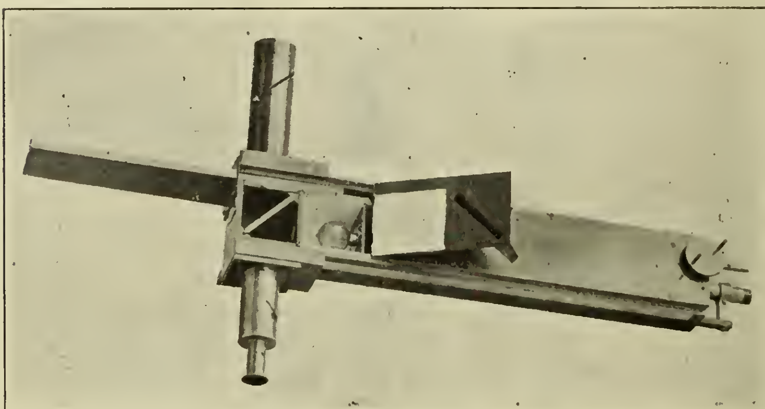



Diagrammatical illustration of the visibility metre.

It was necessary to design and build an instrument and to develop methods for the precise measurement of the quantities, $B_r$ and $B_1$, under practical conditions. After extensive preliminary trials a satisfactory instrument was developed. Several different types, all operating upon the same basic principles, hav-

ing been designed, the type which appeared to be most convenient for practical work was chosen and a complete instrument constructed. This instrument is called a "visibility-metre" and patents covering the basic principles upon which it is constructed and several particular designs have been applied for by the Eastman Kodak Company, in whose Research Laboratory these experiments were conducted. In Fig. 2 is given a diagrammatic sketch showing the arrangement of the essential parts of the instrument, and Figs. 3 and 4 show photographs of the completed instrument.

FIG. 3.



The visibility metre open.

The letter $M$, Fig. 2, indicates a semi-transparent mirror set at 45° to the axis of the instrument, which is coincident with the axis of sight. This mirror reflects about 60 per cent. of the incident light and transmits approximately 20 per cent., the remaining 20 per cent. being absorbed. The secondary axis of the instrument is a line perpendicular to the axis of sight at the point where the reflecting surface intersects the axis of sight. $C$ is a diffusing member composed of pot or flashed opal glass placed perpendicular to the secondary axis. This diffusing surface is illuminated by a light source, $S$, mounted so as to move along the secondary axis. This source is mounted at one end of a brass tube, $B$, on one side of which is the rack, $R_1$. A knurled hand wheel, $N$, is mounted rigidly on a shaft carrying also the pinion,

$P_1$, which engages the rack, $R_1$, thus providing for the movement of the source along the secondary axis by a rotation of the hand wheel, $N$. A second pinion, $P_2$, in mesh with $P_1$, engages the rack, $R_2$, which is rigidly attached to the frame carrying the neutral gray non-diffusing optical wedge, $W$. This wedge varies continually in opacity from one end to the other, and is so arranged as to move across the axis of sight. The object lens, $L_1$, is of such focal length that the object of which the visibility is to be measured is imaged sharply at the point where the reflecting surface, $M$, intersects the axis of sight. This lens is adjustable in position, so that either near or far objects may be imaged in

FIG. 4.

The visibility-metre closed.

the proper plane. The eye lens, $L_2$, is of such power that the magnification of the system is unity, thus giving a retinal image of the same size as when the object is viewed with the naked eye. The lens $L_2$ enables the eye to see clearly defined the image formed by the lens $L_1$. The mirror $M$ may be replaced by a simple photometric field for the purpose of measuring brightness, it being necessary to measure $B_1$ in order to obtain the visibility value. The details of the interchangeable field are shown in the small right-hand drawing of Fig. 2.

In order to increase the sensibility of the instrument in the measurement of $B_v$, a strip of clear gelatine film is placed over one-half of the field, thus increasing the reflecting power of that half by about 8 per cent. If $a$ be the half of the field thus covered, it will for a given position of the source, $S$, cause a brighter veiling glare to appear as superposed over the object and back-

ground than the other half of the field, $b$. Now, if the object be so adjusted in the field of the instrument that the line between the two halves of the field bisects (approximately) the object, that part of the object in the field $b$ will still be visible when the other part (that in field $a$) has been completely obscured by the veiling glare of that part of the field. In this way certain limits are set between which every setting must be made. If it is desired to decrease the difference in brightness between the two parts of the field (in order to narrow the limits of the setting), this may be done by making the reflecting powers of one-half of the field any desired amount greater than the other. This is easily accomplished if the reflecting surface is made by depositing the reflecting metal on the glass by a cathodic discharge.

The photometric field is made by covering one-half, $c$, of the small circular opening with a piece of highly reflecting matt paper. The white paper is illuminated by the source, $S$, and the other half, $d$, being open, permits the eye to see the image of the background formed by the lens $L_1$. The line between $c$ and $d$ (when the photometric field is in a position for use) lies at the intersection of the axis of sight with the secondary axis and hence in the plane in which the object is imaged by the lens $L_1$. The circular field, $e$, surrounding the photometric fields, $c$ and $d$, is made of grey matt paper. This is the type of field actually used in the instrument, but any of the well-known types, such as a Lummer-Brodhum cube, may be substituted if desired, the chief requirement being a sharp dividing line lying in the image plane. These two fields are mounted in a small metal frame, sliding in milled metal ways placed perpendicular to the plane through the axis of the instrument. Stops are provided so that each field may easily and quickly be brought into position with the axis of sight passing through the centre of the field being used. A light filter is placed at $F$. This filter is of such quality that the light from the source $S$, after passing through the filter, matches in color the light which illuminates the object and background. A graduated scale, $T$, is fastened rigidly to the case which incloses the source. An index, $I$, attached to the source or its supporting member moves along this scale, indicating at all times the position of the source, $S$, and wedge, $W$, with reference to the axis of sight. The scale is so calibrated that from the position of the index at any instant the brightness of the glare field, $B'_F$, and the opacity of the wedge on

the axis of sight can be determined. By turning the hand wheel $N$, the source, $S$, and the wedge, $W$, are caused to move simultaneously and in such fashion that an increase in the brightness of the veiling glare, $B_1$, is accompanied by an increase in the opacity of the wedge on the axis of sight. This increase in opacity causes a diminution in the intensity of the light which reaches the eye from the object and background.

Now the light transmitted by the diffusing member, $C$, is reflected into the eye, appearing to come from the image of that surface. Thus diffuse white light is caused to enter the eye from a point between the eye and the object being observed, increasing the apparent brightness of both object and background by the same amount and causing the ratio of $B_1$ to $B_2$ to be lowered. At the same time the wedge, $W$, is introduced, causing a proportionate reduction in the apparent brightness of $B_1$ and $B_2$.

It will be seen, therefore, that the action of the instrument is exactly analogous to the action of material particles distributed throughout the foreground space, *i.e.,* the production of a veiling glare between the eye and the object and the absorption of a certain percentage of the light reflected or emitted by the object and background. Now, if the source and wedge be moved to such a position that the object is just visible in one part of the field and not visible in the other, a setting is obtained from which the values of $B'_v$ and $D_a$ can be determined.

In our fundamental equations, $B_v$ was defined as the brightness of the veiling glare which when superposed over object and background will reduce the visibility to zero or a just perceptible value. It will be noted that as no term covering the decrease in brightness due to absorption of light in the foreground space appears in those equations, it is inferred that the entire loss of visibility is produced by the veiling glare, $B_v$. Now the effect of the introduction of an absorbing member, such as the wedge $W$, is merely to decrease the amount of veiling glare required to reduce the visibility to zero. It is not feasible in practice to produce the extinction of visibility by a veiling glare alone, due to the fact that the values of $B_1$ and $B_2$ are so high that a source of very high intensity would be required to give the required value of $B_v$. As it is desirable to make the instrument as portable as possible, such sources cannot conveniently be used on account of the excessive weight of storage batteries required to operate them. By using

an absorbing wedge in the axis of sight a much smaller lamp may be used. Such procedure does not in any way interfere with the correct determination of $B_v$. In order to obtain the maximum possible illumination on the diffusing member with a lamp to given energy consumption, the interior walls of the chamber inclosing the source, $S$, are painted white. This tends to increase the brightness of the diffusing member and also to increase the uniformity of illumination on this surface, which is extremely desirable. This painting of the interior walls prevents the use of the inverse square law in computing the illumination on the diffusing surface from known values of intensity of source and distance between source and surface. This, however, does not interfere in any way with the operation of the instrument.

For a given ratio of $B_1$ to $B_2$ the value of $B_v$ required to produce a loss of visibility is directly proportional to the absolute values of $B_1$ and $B_2$. Thus by reducing the apparent brightness of $B_1$ and $B_2$ to one-tenth of their actual value by means of the member $W$, only one-tenth of the amount of veiling glare from the surface of $M$ will be required to produce a given lowering of visibility. The brightness of the glare field of the instrument will be designated by $B^1{}_v$ and should not be confused with the term $B_v$ appearing in the equations. The value of $B_v$ is computed from those of $B^1{}_v$ and $D_a$ (the density) or $T_a$ (the transmission) of the wedge $W$ at the point through which passes the axis of sight.

The statement that the value of $B_v$, appearing in the fundamental equations, is directly proportional to $B_1$ or $B_2$ and hence inversely proportional to $T_a$ rests upon a basic assumption which should be mentioned at this point. In order for this to be true, $k$, the contrast factor of the eye, must remain constant. That is, the total field of brightness to which the eye is subjected must not change sufficiently to cause an accompanying change in $k$. This factor is satisfied in the instrument by so adjusting the density gradient of the wedge $W$ and the linear velocity of the wedge relative to that of the source, that the total field of brightness, $B_t$, of the instrument remains sensibly constant regardless of the position of the members relative to the axis of sight. It is not possible to obtain exact constancy of $B_t$ for all values of $B_1$, but $B_t$ can be kept within the range for which $k$ is constant. However, in case $B_t$ should vary beyond the specified range of values, it is

still possible to compute $B_r$, provided the resulting change in the value of $k$ is known. If $B_t$ is measured, which can easily be done, the corresponding values of $k$ may be obtained. In practice it is found that $B_t$ can be kept within the required limits in almost all cases by choosing a wedge of proper density gradient and by adjusting the number of teeth on the pinions so that the desired relative motions of $S$ and $W$ are obtained.

The above consideration shows that it is not necessary to exactly simulate in the instrument the relations existing in nature between the values of the veiling glare brightness and the opacity arising from the particles suspended in the foreground space. Since this relation is not constant for all natural conditions, being dependent upon the nature, size and spatial distribution of such scattering and absorbing particles, it would be quite impossible to make a single instrument exactly simulating all possible conditions resulting in lowered visibility.

Now it will be noted by referring to the theoretical treatment that

$$V = \frac{B_1}{B_v}.$$

It is necessary, therefore, to determine the value of $B_1$. This is done by substituting for the glare field, $X$, in Fig. 2, the photometric field, $Y$. The instrument being calibrated as a brightness photometer, the value of $B_1$ is read directly from the scale when a photometric balance exists between the fields $c$ and $d$. The field $d$ is filled by the image of the background.

In order to obtain a value of $W$, the weather coefficient, which is defined by the expression,

$$W = \frac{B_1}{E_2},$$

it is necessary also to determine the value of $E_2$, the illumination on the object plane. This may be done by measurement of the brightness, $B_o$, of a surface in the object plane of which the reflection factor, $R_o$, is known. Such a surface is termed a test plane and is made by covering a frame of the proper size with canvas or sail cloth painted with several coats of a matt white paint. The reflection factor, $R_o$, of this surface is carefully determined by suitable laboratory methods. When determinations of visibility are to be made, this test plane is fixed in the object plane so that its

brightness may be read from the designated point of observation.

The procedure in taking a complete visibility reading then consists of three steps:

(1) With the glare field in position the instrument is so set that the image of the object occupies a position in the field $X$, Fig. 2, such that the dividing line between $a$ and $b$ approximately bisects the image. The hand wheel $N$ is then turned until the object is just visible in field $b$, and is invisible in field $a$. The position of the index on the scale $S$ is then read, giving the scale reading $S_1$.

(2) The photometric field is thrown into position and the instrument so aligned that the image of the background fills the portion $d$ of the field $Y$, Fig. 2. $N$ is then turned until $d$ and $c$ are equal in brightness and the position of the index being read gives the scale reading $S_2$.

(3) The alignment of the instrument is changed so that the image of the test plane fills the field $d$ and a photometric balance is again made by turning $N$. The position of the index now gives the third scale reading $S_3$.

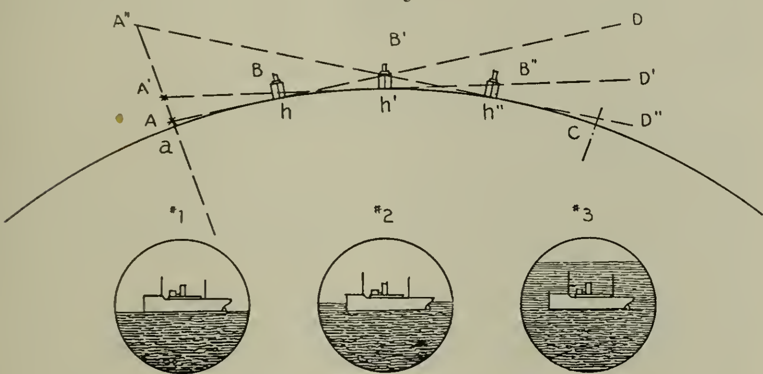
### THE VISIBILITY OF SURFACE CRAFT FROM A SUBMARINE.

The treatment of the subject of the visibility of an object thus far has been based upon certain simplifying hypotheses, the chief of which are: ($a$) an object uniform in color and brightness; ($b$) a background also uniform in color and brightness. Let us now analyze the problem of the visibility of a ship observed from a submarine and determine how nearly this practical case approaches to the ideal case based upon the stated hypotheses.

First let us consider the background against which the ship must be viewed. In the general case of a ship at sea the background may be composed either of sky or water or some combination of the two. The ratio of the sky to sea in any case depends upon three factors. In Fig. 5 let the line $ah'c$ represent the surface of the sea, $A$, the point of observation, and $B$, an elevation of the ship observed. The factors governing the proportion of sky and sea composing the background in any case are: (1) the distance $x$, represented by the line $Aa$, the height of the point of observation above the sea level; (2) the distance $y$, the line $AB$ representing the distance between the point of observation $A$ and the ship observed, $B$; (3) the height of the observed ship, which

we will call $z$. The magnitude of $x$ determines the distance between the point of observation and the horizon line, which may be defined as the line which is the locus of the points of tangency between the spherical surface formed by the surface of the sea and all lines passing through the point of observation and tangent to this spherical surface. The positions of the horizon lines for the three observation points, $A$, $A'$ and $A''$, are represented in Fig. 5 by the points $h$, $h'$ and $h''$, respectively. Let the distance from the horizon line to the point of observation be indicated by the symbol $H$. The small inserts, 1, 2 and 3, represent the appearance of the visual fields when the boat, $B$, is observed from the three

FIG. 5.




The ratio of sky to sea in the field of the periscope.

points $A$, $A'$ and $A''$. In 1 it will be seen that the entire background against which the boat is seen is sky. This is the case where $y = H$. In 2, part of the background is sky and part sea. Here $y < H$. In 3, the entire background is sea. Here also $y < H$. It will be seen, therefore, if $y$ is equal to or greater than $H$ that the entire background will be sky. These figures are presented merely for the purpose of illustration, numerical data being presented in another part of this report from which the actual proportions of sea and sky composing the background for any specified values of $x$, $y$ and $z$ may be computed.

Study of the conditions of observation from a hostile submarine preparing to attack a vessel reveals the fact that in practically all cases $y$ is greater than $H$. When a submarine is operating on the surface, the distance, $x$, may be as great as 25 feet,

thus giving an approximate value of $H = 12{,}000$ yards. But since the submarine itself must avoid being seen by an observer on the boat to be attacked, this elevation of observation point is only available when the distance, $y$, is great. When running awash, the value of $x$ is approximately 10, giving a value of $H = 9000$ yards. When submerged, the value of $x$ is seldom over 1 to 2 feet, giving values of $H$ from 4000 to 4500 yards. Thus, in order for the surface craft to be seen against anything but a background composed entirely of sky when observed from the submerged submarine, the distance, $y$, must be less than 4000 yards; when running awash it must be less than 9000 yards, and when running on the surface must be less than 12,000 yards. It is evident from these considerations that the background to be dealt with in this problem of low visibility is sky only, and hence uniform as considered from the standpoint of its general nature.

Now from the standpoint of visibility it is not necessary to consider the brightness and color of the sky as a whole but only of that small portion which appears to immediately surround the observed ship, forming the background against which the ship is seen. Given an observed boat 400 feet long, 100 feet high (to the tops of the masts), and with the value of $y = 4000$ yards, the visual angle subtended at the eye in the horizontal plane will be approximately 2°, and in the vertical plane 30′. The portion of the sky, therefore, which must be considered as the background of any instant is only slightly larger than this, subtending at the eye a vertical angle of 45′, and a horizontal angle of 3°. We are concerned with the brightness and color of this field, or, in case the values of these factors are not constant, for all points within this area, with the nature of the variation of brightness and color occurring within the specified area. If this area is uniform in brightness and color, then for low visibility the ship as observed from the specified point of observation should appear of the same color and brightness, uniform over the entire visible surfaces. If the area of sky being considered is not uniform in brightness and color, then the ship, in order to have low visibility, should be so painted that, as viewed from the specified point, the same general variation in color and brightness occurs on the visible surfaces as occurs on the sky background. For instance, if the background appears to be striped in the vertical direction due to alternately high and low values of $B_1$, then the ship should

appear with perpendicular stripes alternately light and dark. However, extended observation shows that considering a portion of the sky, the lower boundary line of which is the horizon, subtending a vertical angle at the eye of 45′, practically no variation in either color or brightness exists within such a relatively small area. The background, therefore, is in almost all cases uniform, and hence conforms with the assumptions made in the theoretical treatment.

Now let us consider the appearance of the ship. Here both vertical and horizontal surfaces distributed in three dimensions must be considered. Due to the nature of such structures some surfaces receive much greater incident illumination than others. Hence, if all of these visible surfaces are painted with a perfectly matt paint of fixed composition, thus causing all surfaces to have the same reflecting power, with the diffuse conditions of lighting such as occur on dull, overcast days, a great variation in the brightness of the various surfaces may exist. Considering further the fact that all painted surfaces reflect some light specularly and that conditions of more or less direct illumination (such as occur with the sun not at all or only partially obscured by clouds) must be taken into account—it is evident that the existence of regions on the ship of pronounced high light and shadow will exist.

It is clear, then, that our original hypothesis of an object uniform in brightness and color does not apply to the practical case. The failure of this assumption to hold does not in any way invalidate our methods of measuring the visibility even when applied to cases where the object is not uniform in brightness and color. In case the visibility of an object in a given case is due to this lack of uniformity the magnitude of its visibility may still be evaluated by the veiling glare required to produce a disappearance of that lack of uniformity.

In attempting to obtain low visibility by application of paint to the ship the question of highlights and shadows should receive careful consideration and effort should be made to eliminate them as completely as is possible, thus producing an object approximately uniform in brightness and color when viewed from the specified point of observation. The details of working out such a scheme vary with the peculiar nature of the structure under consideration. General laws can, however, be outlined. All surfaces which by nature of their position receive excessive illumina-

tion or reflect excessively in the direction from which observation is to be made should be painted so as to have a lower reflecting power than other surfaces. All specular reflection should be reduced to a minimum by the use of matt paints. Surfaces which by virtue of their position receive less illumination than the average should be raised in reflecting power by the use of lighter paints. Shadows may also be lightened by increasing the incident illumination. In some cases this may be done by painting with the whitest paint obtainable all contiguous surfaces which cannot be seen from the specified point of observation. Thus in some cases it is of advantage to apply white paint to certain portions of the deck and to the under sides of overhanging superstructures. In some cases it may not be possible even by use of white paint to sufficiently lighten shadows. One instance of this is found in the case of the shadow in the throat of a ventilator. In such case a surface which receives sufficient illumination may be interposed between the point of observation and the shadow to be eliminated.

The essential points of this section may be summarized as follows:

(1) The background to be considered is composed entirely of sky.

(2) This area of sky to be considered subtends an approximate visual angle of 45′ in the vertical direction, of 3° in the horizontal.

(3) This area is very nearly uniform in brightness and color.

(4) The object (the observed boat) is not in general uniform in brightness and color.

(5) By special treatment a close approach to uniformity can be obtained.

(6) For low visibility an object viewed against a background which is uniform in brightness and color should also be uniform and of the same brightness and color as the background.

(7) For low visibility an object viewed against a background not uniform in brightness and color should exhibit a distribution of brightness and color similar to that prevailing in the background.

(8) Visibility due to lack of uniformity may be measured by the same general method, *i.e.*, the superposition of a veiling glare over object and background.

## EXPERIMENTAL RESULTS.

The theory upon which the measurement and specification of visibility is based having been briefly considered and an instrument devised by means of which the visibility of any object may be measured, it remains now to discuss the practical application of these methods to actual cases.

It has been shown that the background available in case of the observation of a surface craft from a submarine is composed almost entirely of sky and that this sky is uniform in color and brightness. For low visibility the boat must also be uniform. Hence a flat board, cut so as to represent the profile of the boat to be observed and painted uniformly represents satisfactorily, from the standpoint of visibility, the optimum condition for low visibility. While such models do not represent the actual appearance of a structure distributed in three dimensions, they do represent the ideal which may be approached by a system of painting which eliminates as nearly as possible all highlights and shadows. Such profile models are, therefore, quite satisfactory for this phase of the work, which deals with the determination of the best brightness and color for the production of low visibility.

Referring now to the theoretical treatment and the nomenclature adopted, it will be seen that the conditions for invisibility are that:

$$B_1 = B_2 = R_2\ E_2,$$
$$H_1 = H_2,$$
$$S_1 = S_2.$$

The factors $B_1$, $H_1$ and $S_1$ are natural characteristics of the particular sky background being considered and hence are fixed. The term $E_2$ is also a factor beyond our control. The three factors subject to control are, therefore, $R_2$, $H_2$ and $S_2$, and it is with the experimental determination of the best values of these three terms for various conditions of the weather that this section deals. It is convenient to divide the work into parts:

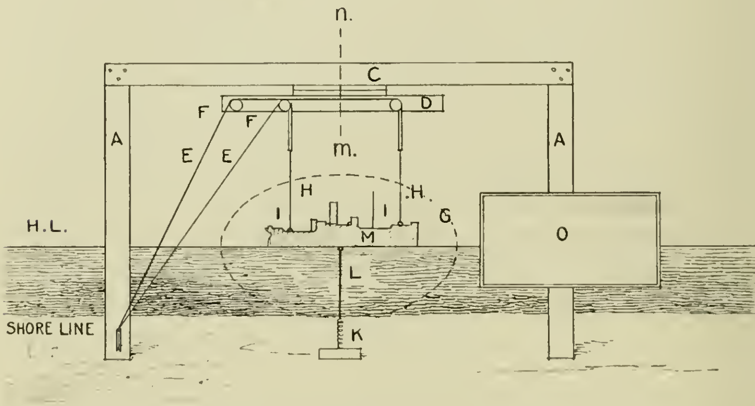
(1) The determination of $R_2$.

(2) The determination of color ($H_2$ and $S_2$).

The experimental work was carried out at Rochester, N. Y., on Lake Ontario, and at sea. In order to obtain natural lighting conditions and to use as a background a portion of sky just above a water-line sky, a station was established on the shore of Lake Ontario. To hold the models in proper position for observation,

a rack with an arrangement for suspending the models was erected. This rack, illustrated in Fig. 6, was erected as close to the water's edge as possible. The two uprights, *A, A,* were connected at the top by the crosspiece *C.* The member *D* was suspended from *C* and so arranged that it could be rotated in a horizontal plane about the vertical axis represented by the line *mn.* To the ends of the sash cords, *E, E,* running over the pulleys, *F, F,* on the member *D,* were attached fine piano wires, *H, H,* terminating in hooks, *I, I.* In placing a model in position for observation the hooks, *I, I,* were inserted into the eyes located along the top of the model, *M,* and an attendant operating the

FIG. 6.




The model rack.

cords raised the model to such a position that from the point of observation the lower boundary of the model appeared to be coincident with the horizon line, *HL.* One end of a strong spiral spring, *K,* was attached to the ground directly below the model, the other end termination in a piano wire leader, *L,* which was hooked into an eye on the bottom of the model, thus preventing the model from being displaced from the desired position by any wind that might be blowing at the time. On one of the uprights the test plane, *O,* was placed at the same height as the model, thus permitting the test plane to be brought into the field by simply changing the orientation of the visibility metre on its tripod.

The point Station 1, Fig. 7, from which most of the observations were made, was due south from the model and at such a dis-

tance that the visual angle subtended at the eye by the model was equivalent to that subtended by a boat 300 feet long when at a distance of 6000 yards from the observer. Readings, however, were taken at other points, Stations 4 to 7, such that the equivalent distance for the 300-foot boat was varied from 2000 to 18,000 yards. By rotating the member *D,* readings could be taken with the boat at any angle to the axis of sight, thus giving visibility values for a boat at any desired course. Observations were also taken from points southwest, Station 2, and southeast, Station 3, from the model and with the models at various angles,

FIG. 7.

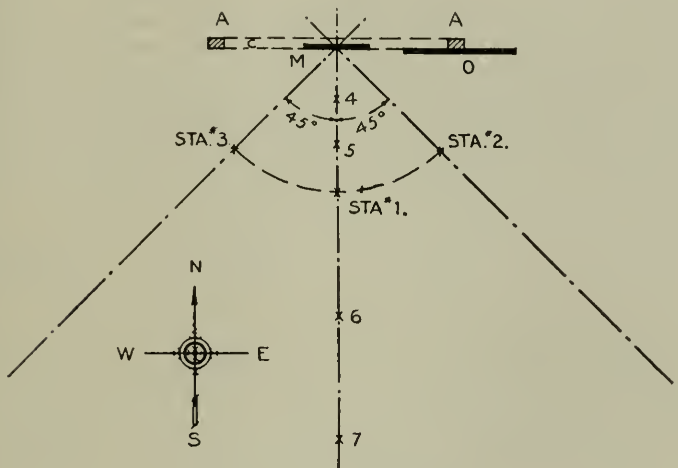



Diagram of the observation stations.

to the line of sight. Figs. 5 and 6 are not drawn to scale. The actual distance between the model and the nearest point of observation, Station 4, was approximately 100 feet, while the distance between the centres of model and test plane was 8 feet, so that the model set parallel to the test plane and the line of sight was practically perpendicular to both test plane and model. The models used were approximately 5 feet long by 6 inches high. Therefore, an actual distance of 50 feet between model and point of observation causes the same visual angle to be subtended by the model as would be subtended by a ship 300 feet long at a distance of 1000 yards. Station 1, upon which the great majority of observations were made, was at a distance of 300 feet from the model.

(*To be concluded.*)

**Motor Cars at Home and Abroad.** (*Machinery*, London, vol. xiv, No. 354, p. 446, July 10, 1919.)—There is a motor vehicle registered in the United States for every twenty-four persons; in Canada the proportion is probably one to each fifty; in England, one to two hundred; in Denmark, one to three hundred; and in France, Belgium, Holland, Switzerland, and Germany, about one to every four hundred. In 1917 it was estimated that Italy had one car to each 1000 of the population; Portugal, to each 1690; Spain, to each 1900; Austria-Hungary, to each 2650; and Russia, to each 5000. In Australia there was one car for each 140 of the population, and in South America as a whole, one for each 1430. Many a minor city in the United States has more cars than the whole of China or Japan. France for many years headed the list of automobile exporting nations, followed by Great Britain, the United States, Italy, Germany, and Belgium. In the United States the domestic requirements were so great that the majority of the cars were absorbed at home. British and European motor builders have multiplied their plant and equipment ten times in four years and yet their combined capacity is still behind that of the United States. It is stated that one American factory intends to manufacture within one year as many cars as the entire British output for 1914. The price of this car is expected to be approximately from $600 to $750.

**Preparation of Glycerol by Carbohydrate Fermentation.** SCHWEIZER. (*Helvetica Chim. Act.*, vol. ii, p. 167, 1919.)—Pasteur in 1857 found that ordinary alcoholic fermentation is attended by the production of a small amount of glycerol. He obtained nearly four parts by weight from 100 parts of sugar. Later, Laborde made investigations as to the influence of the amount and character of the yeasts used, and obtained about double the yield that Pasteur obtained. The production of glycerol depends largely on the nutritive powers of the solution. High nutrition increases the yield, but it seems to have no correlation with the production of alcohol. Schweizer's most successful experiments were carried out with the addition of sodium sulphite as a reducing agent, it having been found that this is favorable to the production of glycerol. The following experiment is given. Fifty grammes of sucrose were dissolved in 500 c.c. of water, 10 grammes of pressed yeast added, and then 30 grammes of sodium sulphite in three portions. After twenty-four hours' fermentation the glycerol produced amounted to 18.72 per cent. of the sucrose used. It is not stated whether the sodium sulphite was crystallized or anhydrous, but probably it was the former. A similar experiment carried out with active aëration gave only half the yield of glycerol. Schweizer states that the method was used by the Central Empires as a source of glycerol on account of the shortage of fats. No biologic examinations of the yeasts are recorded, nor is any statement made as to production of glycerol from the cheaper carbohydrates. An interesting field of research must be offered along this line. H. L.

# AIR FLOW OVER REAR DECK OF BATTLESHIP PENNSYLVANIA.*

BY

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In January, 1918, the Navy model of the battleship *Pennsylvania* was tested in the 8′ × 8′ wind tunnel to determine aerodynamical and structural conditions suitable for landing light airplanes upon the after-deck of the full-scale ship. The model was tested first in its natural condition, then with a shelving deck placed above the rear part in a manner presently to be described.

The experiments here outlined were made by Messrs. R. H. Smith, W. H. Gornall and G. J. Chaillet; the illustrations were prepared by Mr. M. T. Birch—all members of the Aeronautics Staff. Major B. L. Smith, U. S. M. C., indicated what explorations should be made and under what conditions.

### TEST OF MODEL IN ITS NATURAL CONDITION.

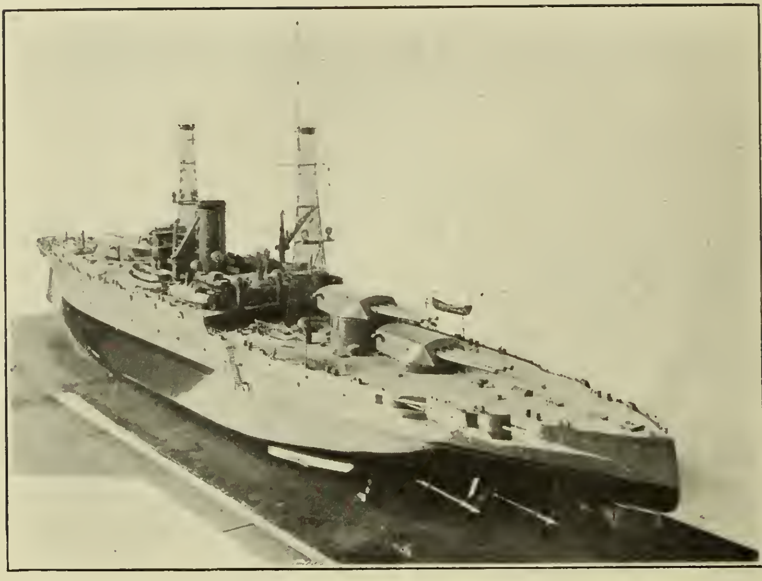
*Battleship and Original Model.*—Fig. 1 gives the general appearance of the *Pennsylvania* model constructed to a scale of 1 in 48. The chief dimensions of the ship are: length 600 feet, beam 97 feet, height of the rear deck above the water line 25 feet.

*Method of Test.*—The unaltered model was first placed upright on the floor of the tunnel, so that its plane of symmetry was midway between the side walls, and its rear deck was under the window in the tunnel ceiling, where it could easily be observed and photographed. The speed of the general air stream was then held at 30 miles per hour, and the velocity about the model was measured with a pitot-tube held in the vicinity of the stern at distances corresponding to 20-foot intervals horizontally rearward, and 5, 15, and 25 feet vertically, above the main deck of the full-sized craft. Table I and Fig. 2 give the wind speed and the lines of equal velocity at these stations; first in the plane of symmetry, then in a parallel plane 24 feet from it.

Fine steel wires were then strung across the tunnel at rear-

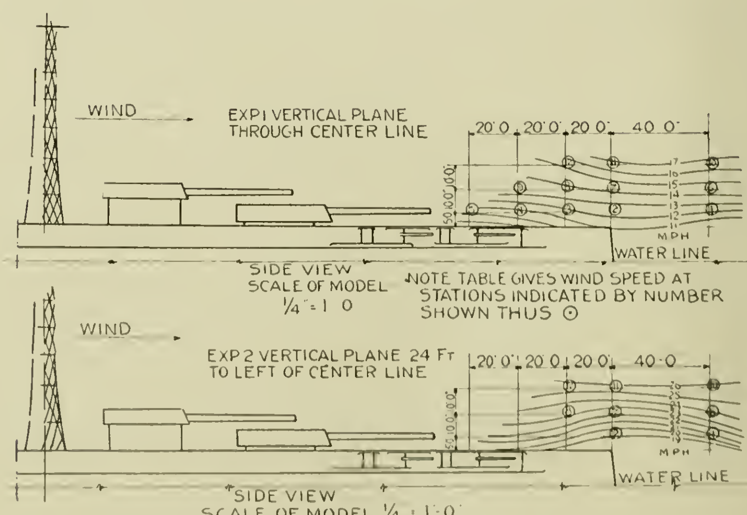
* Communicated by the Author.

FIG. 1.



Model of *Pennsylvania.*

FIG. 2.




Flow over rear deck of *Pennsylvania* at 30 M.P.H.

ward distances corresponding to 48 feet on the full-size craft, and to these were moored, at 8-foot intervals, short silk threads, as portrayed in Fig. 3. With long fluttering threads cleaner photographs were obtained by stopping the wind after the threads had assumed their natural positions. Fig. 4 illustrates the direction of flow, thus observed, in three horizontal planes whose distances above the rear deck were, respectively, 24, 36 and 48 feet.

The model was then held with its plane of symmetry horizontal, its deck under the ceiling window, and its base screwed to planking parallel to the side wall. The same general scheme was

Table I.

*Battleship Pennsylvania Model. Velocity of Air over Rear Deck and Stern. Wind Speed 30 Miles per Hour.*

| Station | Air speed in miles per hour at various stations | |
|---|---|---|
| | In vertical plane through centre line | In vertical plane 24 feet to left of centre line |
| 1 | 11.5 | 20.4 |
| 2 | 12.2 | 19.1 |
| 3 | 11.1 | .... |
| 4 | 10.6 | .... |
| 5 | 9.9 | .... |
| 6 | 14.6 | 24.6 |
| 7 | 14.1 | 22.4 |
| 8 | 13.7 | 23.4 |
| 9 | 13.3 | .... |
| 10 | 16.3 | 25.1 |
| 11 | 16.5 | 25.7 |
| 12 | 14.9 | 25.4 |

employed for observing the flow; first in the plane of symmetry, then in a parallel plane 24 feet distant on the port side, as shown in Fig. 4 and Fig. 5.

*Results.*—The equal-velocity lines in Fig. 2 and the direction lines in Fig. 4 show a pronounced interruption of the airflow near the deck, due mainly to eddies set up by the rear turret. This disturbance is unchanged when the rear turret is swung through 90°, as illustrated by Fig. 6.

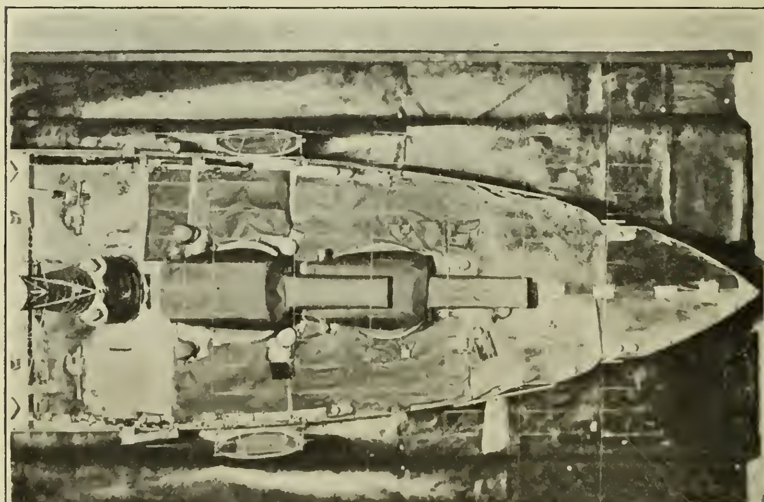
*Conclusion.*—Difficulty would be experienced in landing airplanes in the disturbed air over the rear deck of the *Pennsylvania* battleship in its unaltered condition. A shelving deck above the

plane of the rear turret would insure a smoother flow of the air. It was, therefore, requested that such a deck be added to the model and given a test in the tunnel.

### TEST OF THE MODEL PROVIDED WITH SHELVING DECK.

*The Shelving-Deck Model.*—The original model was now tested; first with a small shelf deck, then with a larger one. In the scale of the full-size craft these measured, respectively, $80' \times 120'$ and $100' \times 180'$. The smaller shelf deck was placed 5 feet above

FIG. 3.



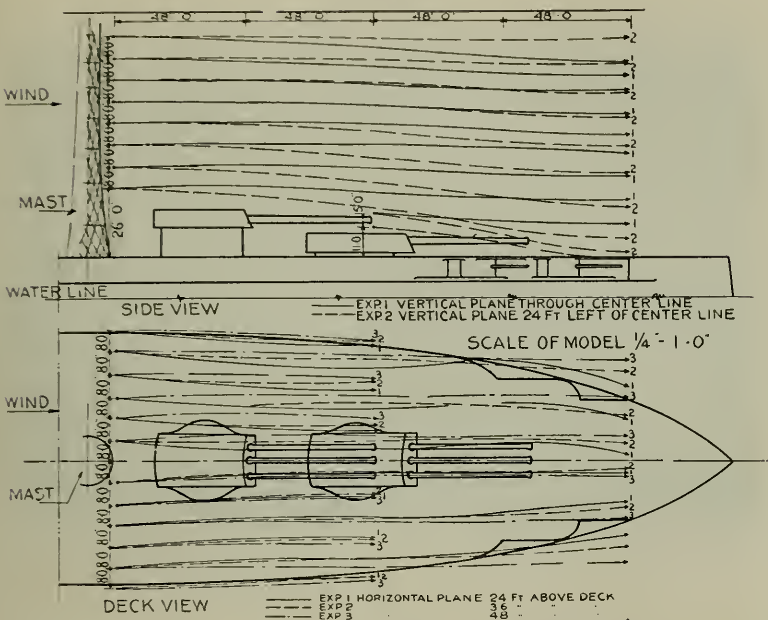
Short threads over rear deck of *Pennyslvania* model.

the main deck, and extended from a point just under the guns of the rear turret to a point just over the stern. The larger deck was 10 feet above the main deck and extended from the mast, rearward, over both turrets and over the stern.

*Method of Test.*—Substantially the same method of tracing the direction of the airflow was used with the model having the shelving deck as with the original one. Fig. 7 shows the arrangement of the wires and the general appearance of the larger deck. The wind speed for these latter tests was 20 miles per hour.

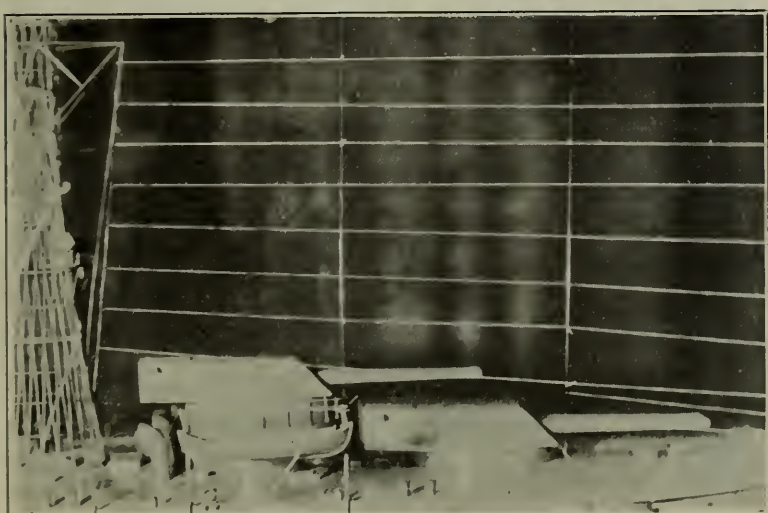
*Results.*—Fig. 8 reveals a continued disturbance of a minor

FIG. 4.



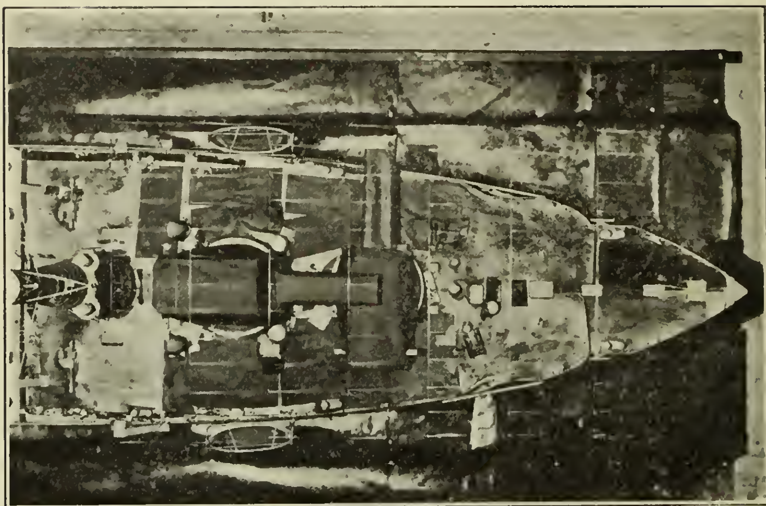

Direction of air flow over rear deck of *Pennsylvania* model.

FIG. 5.



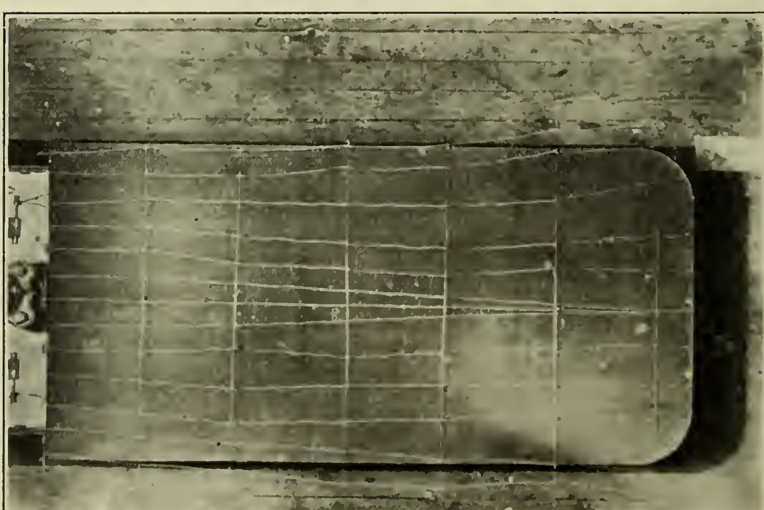
Stream-line threads in plane of symmetry over rear of *Pennsylvania* model, lying on its side.

Fig. 6.



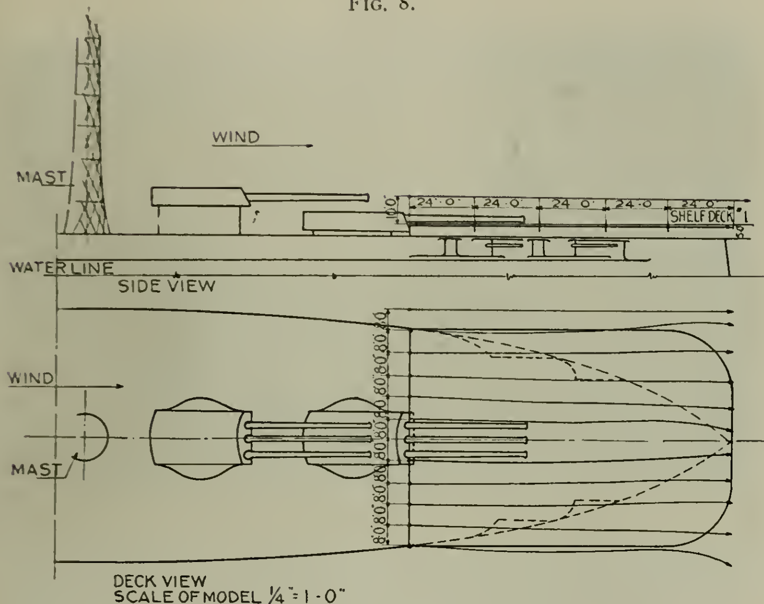
Flow over rear deck of *Pennsylvania*, with rear turret set athwart ship.

Fig. 7.



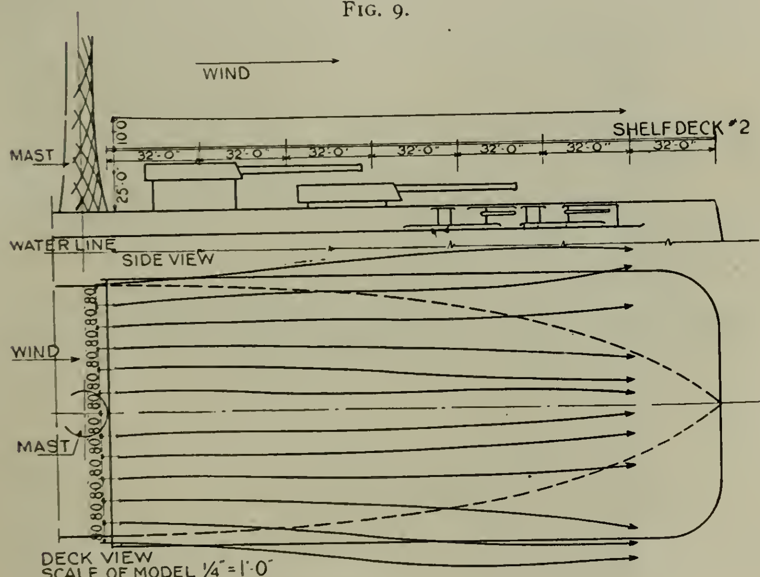
Shelving deck and threads over rear of *Pennsylvania* model.

FIG. 8.



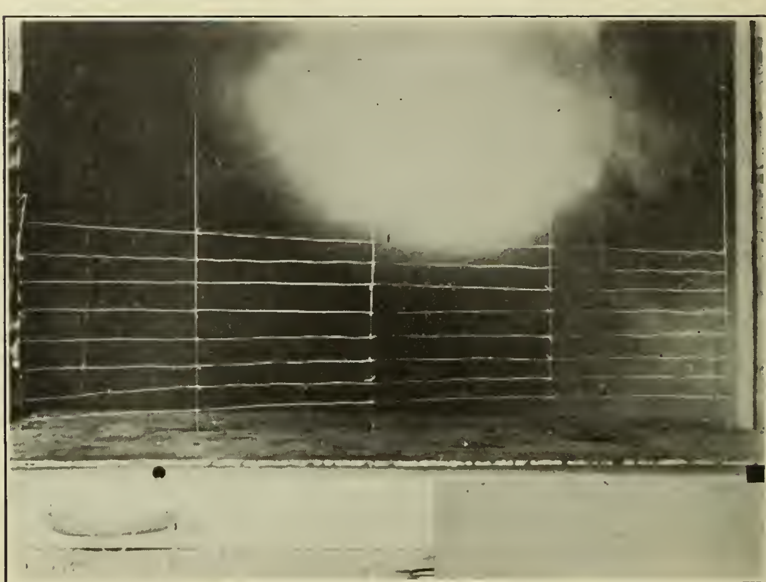

Direction of flow over shelf No. 1 at rear of *Pennsylvania* model.

FIG. 9.



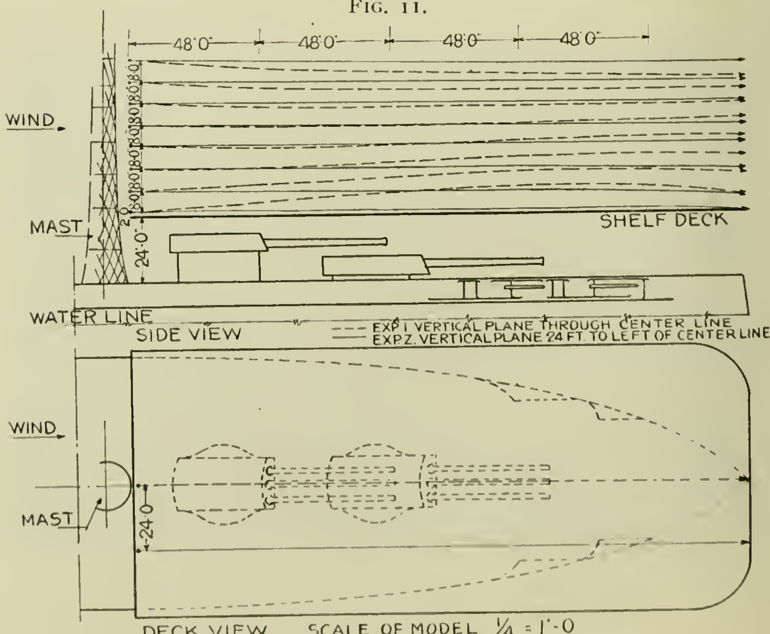

Direction of flow over shelf No. 2 at rear of *Pennsylvania* model.

Fig. 10.



Air flow in plane of symmetry over rear shelf-deck of *Pennsylvania* model, lying on its side.

Fig. 11.




Direction of flow over shelf deck at rear of *Pennsylvania* model.

character at a level 15 feet above the main deck of the ship when furnished with a smaller shelf deck. This is probably due to irregular flow around the hull of the ship. Fig. 9 outlines the direction of flow above the larger shelf deck, in a plane 35 feet above the main deck, and indicates a slight tendency of the air stream to spill over the sides of the shelving deck. The ample beam of the vessel insures a uniform air stream broad enough to afford, with either shelf, a favorable directional flow for landing small craft upon the ship.

*Further Data.*—In a subsequent test, maps of the airflow with the shelf deck in position were determined at 30 miles an hour for the plane of symmetry of the vessel, and for a parallel plane half way out to the edge of the shelf on the port side. It was assumed that the flow in the corresponding plane on the starboard side would be the same. The large shelf deck described in this account was used.

Figs. 10 and 11 show the streamlines for these two planes. The full lines of the diagram indicate that the flow is fairly level and uniform in the planes at either side of the centre line. In the plane of symmetry the flow, indicated by the dotted lines, is considerably less uniform in speed and direction. It would appear from this that the poise of the airplane would be steadiest when flying along the centre line, and not very steady when flying to either side thereof.

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**Concrete Freight Car.** (*Machinery,* vol. xxv, No. 12, p. 1114, August, 1919.)—The first plans for the manufacture of reinforced concrete freight cars dates from 1909, when a patent for such a car was granted. Recently, however, a car of the gondola type was built by a western concern and tested under service conditions. The tests of the car, both empty and loaded, demonstrated its practicability for rough service. In the test without a load, it withstood extremely rough handling and switching. Then the car was loaded with fifty-five tons (10 per cent. overload) of sand and turned over to a switching crew for service handling, which it also withstood without injury. Some advantages claimed for the concrete car are that it will not need painting, will practically eliminate maintenance charges, and will last much longer than the wooden car. As it is unaffected by its cargo, it is better adapted for hauling slag and ashes than a steel car. Plans are said to be under way for the quantity manufacture of these cars. The first one was built with the coöperation of the United States Railroad Administration, which is an indication that extensive production may not be delayed very long.

**Increased Efficiency Taught by the War.** (*Machinery*, vol. xxv, No. 12, p. 1129, August, 1919.)—The war has undoubtedly taught an important lesson in regard to the increasing of efficiency in machine building plants. There are numerous cases on record where to-day manufacturers are turning out a much larger product than five years ago with the same force and equipment. The production per man and machine has been increased by stopping many small leaks. In one instance on record, more machines are being built by a force 75 per cent. of the normal than were formerly built by the full force. In another instance, the production is being maintained by a force two-thirds that of five years ago. Another case may be mentioned where the production has been doubled without materially increasing either the force or the equipment. It is evident that such economies and increased efficiency are necessary in order to cope with the increasing wages, taxes, and costs generally.

The advantages of salvaging small tools such as milling cutters and reamers seem, however, to have been forgotten with the advent of peace. The shops in the Detroit district that devoted themselves to this class of work report that the reclaiming business is quite dull and that at the present time only new tools are wanted and no one is paying any attention to the saving made possible by salvaging. Some manufacturers who devoted themselves to the salvaging of reamers and milling cutters, therefore, have gone into the regular cutter and reamer manufacturing business. Whether there is not a definite economic loss to the nation as a whole in the dropping of the salvaging business is difficult to decide, because it is evident that with the reduction in the prices of high-speed steel the saving by salvaging becomes less, but it is nevertheless likely that a substantial saving could be effected if users of tools utilized the salvaging processes. A comparison between the conditions at this time and during the war in regard to the salvaging of tools would prove interesting.

**Burnt Clay in Concrete Ships.** (*United States Geological Survey Press Bulletin No. 417*, July, 1919.)—Burnt clay was used in 1918 for the first time as an aggregate for concrete in building ships. The war made it imperative that steel be conserved as much as possible, and the experiment of building seagoing ships of concrete was undertaken. It became necessary to make the concrete as light in weight as possible, so various light materials, including pumice, were tried. An aggregate made of burnt shale or clay proved to be a very acceptable substitute for stone and gravel in concrete, and its use reduced the weight per cubic foot from about 150 pounds to 118 pounds or, in some mixtures, even to 100 pounds. This aggregate was made near Birmingham, Ala., at Hannibal, Mo., and at Los Angeles, Calif. Its manufacture was not begun until late in the year, but enough was made to construct a 3000-ton concrete ship, the *Atlantis*, which was launched in December at Brunswick, Ga.

# SPECTRAL ENERGY DISTRIBUTION IN THE ACETYLENE FLAME.*

BY

W. W. COBLENTZ, Ph.D.

Associate Physicist, Bureau of Standards.

In previous papers the writer [1] published data on the spectral energy distribution of the acetylene flame.

In one of these papers [2] an estimate is given of the accuracy attainable in making the observations. It is based upon the deviations of the observations from the mean value; and it is shown that whereas in the red end of the spectrum an accuracy of 0.5 per cent. is attainable (provided the flame stays constant) that an accuracy of 10 per cent. is hardly attainable in the violet. Unfortunately no mention was made of the difficulties and uncertainties in reducing these observed data from the prismatic into the normal spectrum. The purity and slit width factors were probably accurate to 1 per cent. The greatest uncertainty was the correction for absorption in the glass prism or the silver mirrors (or both) in the violet end of the spectrum. Corrections must be made also for diffuse light.

To overcome the difficulties of absorption a spectrometer, consisting of a quartz prism and two plano-convex lenses, was used for measurement in the violet. Not being achromatic, a correction had to be made for change in aperture, with change in focal length for different parts of the spectrum. A recent examination shows that the published data were probably overcorrected (in the violet) for change in aperture; and the utility of such an instrument for making such measurements is to be questioned.

The spectral energy data published by the writer [3] were obtained from a composite curve consisting of measurements from $0.5\mu$ to $75\mu$ made (first) with a mirror spectrometer and fluorite prism, and (second) a glass lens spectrometer with flint glass prism (the absorption of which has been determined), supplemented by measurements, from $0.4\mu$ to $0.5\mu$, made with (third) the quartz lens spectrometer just mentioned.

* Communicated by the Author.

[1] Coblentz, *Bul. Bur. Stds.*, 7, p. 253, 1911; 13, p. 355, 1916.

[2] *Bul. Bur. Stds.*, 7, p. 252, 1916.

[3] *Bul. Bur. Stds.*, 13, p. 355, 1916.

Inspection of the published curve [4] illustrating these data shows a divergence in the region of 0.48μ. Computations made at that time indicated that for the region of 0.48μ to 0.75μ the spectral energy distribution was that of a black body at about 2100° C. (2370° K.); though at that time no significance was attached to it, and hence no mention was made of the fact.

The data presented in the present paper are based upon a careful study of the original spectral energy curve. Some of the deviations noted in columns 2 and 3 of Table I resulted from variations in reading the data from the curves. The data at 0.4μ to 0.5μ obtained with the quartz prism are now given, but little weight, owing to the question of aperture correction. The revised data are given in column 3, while column 2 gives the data as previously published. They are practically the same except in the violet.

In a recent inter-laboratory comparison, by color matching the acetylene flame against a tungsten lamp, Hyde and his collaborators [5] have placed the color temperature of the Eastman Kodak standard acetylene flame at 2360° K. Within the experimental errors of observation the spectral energy distribution of several series of observations of this flame was found to be the same as that of the burner (with 8 mm. slit) used by the writer in the visibility of radiation measurements.

The spectral energy curve of a black body of 2360° K. was kindly computed by Mr. Herbert Kahler and carefully superposed upon the observed data, using a scale which was sufficiently large to eliminate errors (0.5 per cent.) in drawing the curves and reading off the data. These data are given in column 4. Column 5 gives the ratios of observed to computed data for 2360° K. It will be noticed that between 0.48μ and 0.75μ, which is the region in which the radiometric measurements are of importance in the visibility of radiation work, there is as close agreement (± 2 per cent.) between the computed and observed data as can be expected—for, when the errors incident to color match as well as radiometric observations are considered, it will no doubt be conceded that the color match, as well as the radiometric work, has its limitations.

While the writer makes mental reservations as to the efficiency

[4] *Bul. Bur. Stds.*, 13, p. 361, Fig. 3.

[5] This Journal, **188**, p. 129, 1919.

of the color match test in the extreme violet of the spectrum where the eye is very insensitive, and subject to great decrease in sensitivity with age, he concurs in the recommendation made by Hyde that the spectral energy distribution of the acetylene flame (using a certain type of burner) in the visible spectrum is satisfactorily represented by the black body curve at 2360° K., as given in Table I. A difference of 10° or even 50° K. is hardly

TABLE I.

*Spectral Energy Transmission of a Cylindrical Acetylene Flame; Observed and Computed Using Wien's Eq., $C=14350$ and $T=2360°$ K.*

| Wave length | E Observed 1911–1916 | E Revised 1919 | E′ Computed | $\frac{100E'}{E}$ |
|---|---|---|---|---|
| .450 | 11.5 | 10. | 9.2 | 92. |
| .460 | 13.0 | 12. | 11.2 | 93. |
| .475 | 16.0 | 15.0 | 14.6 | 97.3 |
| .500 | 21.9 | 21.0 | 21.1 | 100.5 |
| .520 | 27.9 | 27.5 | 27.3 | 99.3 |
| .525 | 29.5 | 29.2 | 29.2 | 100.0 |
| .540 | 35.0 | 34.6 | 34.6 | 100.0 |
| .550 | 38.9 | 38.9 | 38.9 | 99.8 |
| .560 | 42.9 | 42.9 | 43.1 | 100.4 |
| .575 | 49.8 | 49.8 | 49.9 | 100.2 |
| .580 | 52.2 | 52.2 | 52.4 | 100.3 |
| .600 | 62.1 | 62.5 | 62.9 | 100.6 |
| .620 | 73.0 | 73.3 | 74.0 | 101.1 |
| .625 | 75.7 | 76.1 | 76.8 | 100.8 |
| .640 | 84.7 | 85.0 | 86.0 | 101.1 |
| .650 | 91.1 | 91.2 | 92.1 | 101.0 |
| .660 | 97.4 | 97.6 | 98.5 | 100.7 |
| .675 | 107.5 | 107.5 | 108.0 | 100.4 |
| .680 | 110.9 | 110.9 | 111.3 | 100.7 |
| .700 | 124.6 | 124.1 | 124.1 | 100.0 |
| .720 | 138.5 | 135.7 | 137.2 | 99.8 |
| .725 | 141.9 | 141.0 | 140.5 | 99.6 |
| .740 | 152.0 | 151.0 | 150.2 | 99.5 |
| .750 | 158.9 | 157.9 | 157.2 | 99.5 |

to be considered in view of the great divergence in burners, the effect of humidity, quality of gas, etc.

The independent check by Hyde and his collaborators confirms the direct radiometric observations on the spectral energy distribution of the acetylene flame, in the region of $0.5\mu$ to $0.75\mu$, as used in the visibility of radiation work and leaves the visibility data [6] unchanged.

WASHINGTON, D. C.,
July 24, 1919.

[6] *Bul. Bur. Stds.*, 14, p. 168, 1917.

**Dyestuffs by New Methods.** (*Weekly News Letter*, U. S. Department of Agriculture, vol. vi, No. 51, p. 4, July 23, 1919.)—Cheaper proceses for the manufacture of a number of dyestuffs and medicinal preparations will result, it is believed, from discoveries made by experts of the United States Department of Agriculture who have been investigating ways of making certain sulphonic acids. With a view to helping the chemical industry of the country, the department is offering to coöperate with manufacturers in establishing the process on a commercial scale. The expenses of installation are to be borne by the manufacturing concerns coöperating. Experts of the color laboratory of the Bureau of Chemistry will be assigned to the plants and will assume control of the undertaking.

In all such undertakings, the stipulation will be made by the department that the manufacturing concern is not to divulge anything pertaining to the original process or to any that may be developed later, but that the right to patent any or all of these remains in the Department of Agriculture, these patents, if they are allowed, to be dedicated to the free use of the Government and the public.

In the laboratory experiments the sulphonation of a number of hydrocarbons has been studied and in some cases the laboratory work has reached a stage that large-scale experiments are necessary to prove the value of the process. The work on benzene is most advanced. Sulphonated benzene is used in the manufacture of resorcinol and of synthetic phenol. The laboratory work on the sulphonation of other hydrocarbons is nearing completion.

**Durability of Untreated Piling Above Low Tide.** (*Technical Notes*, Forest Products Laboratory, Madison, Wisconsin.)—In tidal waters the portions of piles above mean low tide, although completely immersed only part of the time, may be practically saturated all the time. Wood constantly saturated with water is not subject to decay, and this fact makes the height to which saturation extends above low tide a question of considerable interest to the designing engineer.

The opinion of a number of engineers and construction companies, expressed in response to inquiries by the Forest Products Laboratory at Madison, Wis., is that untreated piling in water not infested with marine wood-borers will remain sound indefinitely if cut off at half-tide. This height ranges in various ports from 2.3 to 4.5 feet above low water. At certain places on the Atlantic coast, piles cut off at the height of half-tide are still sound after from fifty to one hundred years of service.

Untreated piling is destroyed by marine borers more rapidly than by decay, and the information given would, of course, have no practical use where these organisms are active.

## NOTES FROM THE U. S. BUREAU OF STANDARDS.*

### TESTS OF EIGHTEEN CONCRETE COLUMNS REINFORCED WITH CAST IRON.[1]

[ABSTRACT.]

THE columns were made by Mr. L. J. Mensch, Contracting Engineer, of Chicago, and tested in the Pittsburgh Laboratory of the Bureau of Standards. Although such columns have been in use abroad for several years the tests under discussion are the first of this type which have been made in America.

These columns were 12 inches in diameter (inside 1⅛-inch pitch, 8-guage wire spiral) and were reinforced longitudinally with steel rods and cast-iron tubes. The cast-iron tubes located in the centre of the columns varied in outside diameter from 5 to 7 inches with wall thickness of ⅝ to 1 inch. The column lengths varied from 6 to 14 feet. Tests were made on samples of the cast iron; also on the concrete used which was proportioned by volumes and consisted of one part cement, one part sand, and two parts gravel, hand-mixed.

The behavior of these columns under loading was similar to that of the ordinary type of steel-reinforced columns. Incipient failure was in all cases accomplished by scaling of the outer shell which finally spalled off at the surface of the spiral. This was followed by failure in tension of the spiral reinforcing at the maximum load sustained by the column. The protective shell outside the spiral fails at a strain of .00145 (ave.). This is the same strain at which the test cylinder failed.

The maximum strength of the column is not quite equal to the strength of the cast-iron reinforcement tested independently plus the strength of the usual type of spirally reinforced column. The cast-iron reinforced column has, however, a much less area of concrete.

The columns commenced to scale at 70.4 per cent. (ave.) of the maximum load. Two columns of the same series without cast

* Communicated by the Director.

[1] Technical paper 122.

iron commenced to scale at 89.9 per cent. (ave.) of the maximum. The average maximum total load sustained by the various types reinforced with cast iron and of the same length (10 feet) as the two plain spiral reinforced columns was 81.5 per cent. greater than was sustained by the plain spiral columns. Filling the hollow core of the cast-iron tubes apparently adds 6500 pounds for each square inch of cross section thus filled. Varying the radius of gyration of the cast-iron tubes, the net cross section area remaining constant does not apparently affect the ultimate strength of the column. Cast-iron I sections were used instead of tubes in two of the columns, the results comparing favorably with the tube columns having the same percentage of cast iron.

The following formula for variation of strength with length is derived from these tests:

$\frac{P}{A} = 12{,}150 - 20\,l$, in which

$P$ = mean stress upon total area of column inside the spiral.

$A$ = total area as above.

$l$ = length of column in inches.

In view of the general behavior of spirally reinforced columns just preceding failure it is suggested that a superior type might be developed if the protective shell outside the spiral were applied after the column has been cast and the forms removed. This shell should be of some material possessing the necessary heat insulating qualities and the ability to withstand without failure a considerably greater strain than .0015 (the strain at which unreinforced concrete fails). This method of construction would also make possible a much greater accuracy in the placing of the spiral.

The complete report of these tests contains numerous tables, photographs and diagrams with a discussion of the design of the columns and the results obtained.

## NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

### ILEX VOMITORIA AS A NATIVE SOURCE OF CAFFEINE.[1]

Frederick B. Power and Victor K. Chesnut.

[ABSTRACT.]

SEARCH for a native source of caffeine has demonstrated that an abundant supply may be obtained from a native plant, *Ilex vomitoria*, Aiton. Assays [2] by a method developed by the authors showed the presence, in most cases, of about 1 to 1.5 per cent. of caffeine in dried leaves. Although considerable differences in the caffeine content of the leaves of the plant have been found to exist, these are doubtless attributable to varying conditions of soil and climate. It would, therefore, appear that by the cultivation of the shrub under the most favorable conditions the supply of material for the production of caffeine could be increased to any desired extent.

So far as has at present been ascertained no other North American species of *Ilex* than that above mentioned contains caffeine, and this substance is not contained in the leaves of the European holly, *Ilex aquifolium*, Linné.

Blasting Down Chimneys. (*Engineering World*, vol. xv, No. 3, p. 49. August 1, 1919.)—Following is a method for blasting down chimneys that has been found effective by many engineers. First, remove half a brick in one corner of the chimney at the floor level. Crumble a pound of dynamite and pack it tightly into the back of the hole. Insert a cap and fuse in the charge. Fill the hole with wet sand and pile more wet sand out on the floor, covering the hole entirely to the depth of about 1 foot. Pack the sand down tight so as to get as much resistance to the dynamite as possible. One shot will topple over the chimney as a rule. If the first shot only weakens the structure, however, remove another half brick at the opposite corner and repeat the operation. The second shot, it is claimed, never fails.

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* Communicated by the Chief of the Bureau.

[1] Published in *J. Amer. Chem. Soc.*, 41, 1307–12, August, 1919.

[2] "An Improved Method for the Quantitative Determination of Caffeine in Vegetable Material." Frederick B. Power and Victor K. Chesnut, *J. Amer. Chem. Soc.*, 41, 1298–1306, August, 1919.

**Prospects of Re-habilitation in Germany.** (In the August issue of *The Journal of Industrial and Engineering Chemistry.*)—Corporal Richard D. Zucker, a member of the American Chemical Society, and at the time of writing, with Army of Occupation in Germany, presents his views as to the probabilities of early re-habilitation of the German industrial activities. These depend, he says, largely on opportunites to get certain classes of raw materials, such as copper, tin, nickel, cotton, rubber, gums, essential and fixed oils. Lead and zinc are in good supply within the nation, but the bauxite deposits upon which the aluminum industry depended formerly are mostly in French territory, and it is doubtful if France will allow free purchase, and further, the United States and Canada, well supplied with the mineral, will prove powerful competitors. Zucker calls attention to the fact, which must never be forgotten in discussing the German problem, namely, that the dye-stuff industry can be converted at short notice into a high explosive and poison-gas industry.

One thing which Germany fears in a commercial way is the competition of Japan. Since 1913, Japan's exports to Australia alone increased eight-fold. There is a bitter feeling on account of the strides that Japan has taken in the export of toys, fancy wares, etc., to the United States, South America, Australia, and Europe. The fact that Germany, being closely engaged in warfare, gave Japan an excellent opportunity to expand her business connections, now causes Germany to apply the term "Yellow Peril" to the industries.

Corporal Zucker's observations lead him to suspect that the present leaders of Germany have not wholly abandoned the dream of world domination, and that vigilance will be the only way in which the world can escape another colossal effort to establish the "Deutschtum" and impose "Kultur" on mankind.

H. L.

**War and the Railways.** (*The Baldwin Locomotive Works, Record No. 93,* 1919.)—After winning one of the greatest battles of the war, General Joffre is reported to have said: "This is a railway war. The battle of the Marne was won by the railways of France." And while this statement may, at first sight, appear to be extreme, it is literally true; for success or defeat, in a present-day battle, depends chiefly upon the rapidity with which large masses of men can be moved and the guns served with ammunition; and this must be accomplished by the railways, aided by motor trucks. The amount of ammunition expended during a period of intensive fighting has been almost beyond comprehension. In the attack and defense of Verdun, for example, approximately 60,000,000 shells, representing 3,000,000 tons of steel, were expended in thirty weeks; and the railways moved the greater part of this material to the firing line.

## NOTES FROM THE RESEARCH LABORATORY WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY.*

### WIRE TESTING EXTENSOMETER.

By P. H. Brace.

An extensometer for testing wire and other thin sections has been developed at this laboratory. It consists essentially of a metal block to which two flexible side pieces are attached, the free ends of these carrying rollers. The wire to be tested is clamped at the block and passes between the rollers. Extensions of the wire between the blocks and rollers due to loading the wire results in rotation of the rollers which are held in contact with the wire by the flexibility of the side pieces.

Light from a small straight filament galvanometer lamp passes through a collimating lens to a mirror in the axis of one roller. From there it is reflected to a similarly placed mirror on the other roller, and reflected from there to a white scale divided into millimetres.

An extension of approximately .0001″ causes a movement of the spot of light to a distance of 1 millimetre on the scale. The position of the spot of light could be read to 1/5 mm.

The instrument has been in constant use over a period of several months with very satisfactory results. Specimens have been tested having sectional areas ranging from one-tenth to twenty millionths of a square inch, with satisfactory results. A patent application has been made covering this instrument.

### THE MICROSTRUCTURE OF VERY LOW CARBON STEEL.

By R. E. Bedworth.

Very little information is available regarding the structures which may be produced in steel containing but a few hundredths of one per cent. of carbon. W. J. Brooke and F. F. Hunting[1]

* Communicated by the Engineer in charge.

[1] *Journal of the Iron and Steel Institute,* 1917, No. 2, p. 233.

report an unusual structure found in Armco iron quenched from between 899° and 832° C. They offer the explanation that it is a eutectoid thrown out of solution between these temperatures. A study was made at Yale University, under the direction of Prof. C. H. Mathewson, to throw some light on the nature of this constituent and to determine the effect of various forms of heat treatment on the structure of very low carbon steel. The material used was prepared by Dr. T. D. Yensen at the Westinghouse Research Laboratory by fusing electrolytic iron and carbon in a vacuum furnace. A series of exceptionally pure steels was thus made, with the carbon content ranging from 0.02 to 0.10 per cent. It was found that the "eutectoid" structures could be produced in this pure material by quenching from within the critical range. Further experiments produced conclusive evidence that the so-called eutectoid is not caused by impurities in the metal, but represents the transformation product of the austenite which is stable at the temperature of quenching.

When very low carbon steel is quenched from above A3 a large amount of free ferrite is found, the carbon being present in the form of sorbitic needles scattered throughout the material in the cleavage planes of the original austenite. Annealing at a temperature just below A1 for a long period of time brings about a separation of the sorbite needles into minute globules of cementite. Heating to just above A1, followed by slow cooling, changes the sorbite into very small grains of pearlite uniformly distributed between the small ferrite grains.

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## RESONANCE AND IONIZATION POTENTIALS FOR ELECTRONS IN THE MONATOMIC GASES ARGON, NEON AND HELIUM.

By H. C. Rentschler.

WHEN an electron is accelerated in a metallic vapor two types of inelastic impact are possible. The first type occurs when the moving electron displaces an electron of the atom without detaching it from the atom. The potential through which the moving electron must fall to acquire enough energy to produce this effect is known as the resonance potential. The second type of inelastic impact occurs when the colliding electron separates an electron

of the atom from the sphere of action of the atom and is said to produce ionization.

Experiments were carried out to determine whether the monatomic gases argon, neon and helium show both these types of inelastic impact. A large number of tests were made on these gases, using several methods. The curves obtained indicate that argon has a resonance potential of about 12 volts and an ionizing potential of about 17 volts, while helium and neon do not show the resonance effect.

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## PENETRATION OF MOISTURE IN INSULATING MATERIALS.

By C. J. Rottmann.

MANY samples of standard insulating materials have beeen tested for penetrability of moisture. A large variation in penetration is shown. Untreated papers show immediate penetration, whereas paper impregnated with various insulating compounds, treated cloth or condensation products like bakelite micarta, show very small penetration. None of the standard insulating materials may be called moisture proof.

Where the penetration of moisture is slow, little difference is noticed whether the sheet is in contact with water or the saturated vapor. Several thicknesses of bakelite micarta were used, the penetration in this case being nearly independent of the thickness up to $^1/_{64}''$, which is $1.5 \times 10^{-6}$ gms. $H_2O$ cm.$^2$ per hour. Plotting gms. $H_2O$ against time a small rapid increase in water is first observed followed by a much longer period, where practically no increase in water (time of penetration and dependent upon thickness), and then a gradually increasing amount of water, the slope of the curve remaining almost constant, which value is representative of the rate of penetration.

Several qualitative methods were first tried: (1) Colormetrically, by placing anhyd. $CuSO_4$ or $CoCl_3$ on glass plate upon which is placed the insulating material. Wet blotting paper is weighted down upon the sample and change in color noted upon penetration. Certain water sol. dyes may be also used with good results. (2) Electrically, by conductivity change with increase of moisture measured when insulating material is placed between Hg. surface and weak salt solution. (3) Quantitatively, by collection of moisture in $P_2O_5$ tube, or difference in pressure

of penetrated water vapor when released from liquid air trap by sensitive optical manometer method.

Method now in use may be briefly described as follows: Two 100-c.c. bulbs with stopcocks at necks and common connector for high vacuum system, each having flanged tube 1.5 cm. diameter leading from the side, are so arranged that the ground flanged surfaces fit together so that the apparatus is gas-tight. Through a ground joint in one bulb a weighed $P_2O_5$ tube is introduced. The opposite bulb contains a small amount of $H_2O$ and the whole apparatus may be placed in a position so that the water will come in contact with the insulating material sheet which is held as a diaphragm between the bulb chambers. It is sometimes necessary to use rubber gaskets to make a tight joint between the sample and ground surfaces of the flanged side tubes.

The whole apparatus may be placed so that the water or water vapor in one bulb may come in contact with the diaphragm. Dry air is admitted each time a weighing is made.

Where rate of penetration of $H_2O$ is small, and to eliminate the weighing errors, a pressure difference due to penetrated moisture is measured. In this case a trap attached to the lower end of the dry bulb is used to freeze out the penetrated water vapor. When freezing mixture is taken away the difference in pressure is measured by means of the optical manometer gauge designed by Shrader.[2]

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**An Improved Method of Analysis of Bearing Alloys and Similar Mixtures.** (*Helvetica Chim. Act.*, vol. ii, p. 398, 1919.)—Osterheld and Honnegger describe a method which has given excellent results in their hands and which avoids the use of the more powerful oxidizing. The finely divided alloy is boiled with concentrated sulphuric acid. The procedure is applicable to alloys containing antimony, lead, tin, and copper. The finely divided material is boiled with concentrated sulphuric acid. Even alloys rich in lead are quickly dissolved. Antimony passes into solution as an antimonous compound, tin as stannic sulphate, copper and lead into the ordinary sulphates, which are partly soluble in the acid. By dilution the whole of the lead sulphate can be precipitated. The lead sulphate can be collected on a gooch filter and dried and weighed, the antimony determined by titration with potassium bromate, and subsequently the tin and copper determined also volumetrically. H. L.

[2] *Phys. Rev.*, vol. xiii, p. 321–25.

## NOTES FROM THE U. S. BUREAU OF MINES.*

### METALLURGY OF WULFENITE.

By J. P. Bonardi.

PROBABLY 90 per cent. of the molybdenum produced in the United States during the war period was derived from molybdenite, in spite of the fact that prior to 1915 the wulfenite ores of Arizona supplied the larger part of the molybdenum. This is because of the successful application of flotation to molybdenite and because the deposits of the latter are larger. The wet concentration of wulfenite ore offers little difficulty, but a number of associated minerals—vanadinite, cerussite, anglesite, galena, pyromorphite, and mimetite—come out in the concentrate, rendering its subsequent treatment somewhat difficult. Usually, a concentrate of 15 to 20 per cent. $MoO_3$ is the best that can be obtained, and buyers of concentrate frequently set the latter figure as their minimum content. Wulfenite has the advantage over molybdenite that it frequently has gold associated with it, and both this and the lead are recovered in the treatment of the concentrate. Any of three methods may be used: (1) an acid leach; (2) an alkaline leach; (3) fusing with something that will reduce the lead to the metallic form and take the molybdenum into the slag. The first has so many disadvantages compared with the other two as not to merit much consideration. Of the various alkalies, sodium sulphide is, perhaps, the most satisfactory, as the molybdenum goes into solution as sodium molybdate, while the lead and precious metals remain in the residues. This process is used by at least one company in the United States at the present time. The high-grade calcium molybdate thus produced can be used for the production of ammonium molybdate, ferro-molybdenum or added directly to the steel in the manufacture of alloy steels. By fusing with soda ash, caustic soda and coal, the lead is recovered in the form of bullion. The sodium molybdate thus formed can be leached from the slag and the metal precipitated in the form of calcium molybdate, which can be utilized as stated above. In one of the experiments a recovery of 96.7 per cent.

* Communicated by the Director.

was made on the molybdenum and of 98.5 per cent. on the lead, and it is estimated that a 90 per cent. extraction of both would represent commercial practice. At present prices there is a difference of $270 between the value of the products and the cost of the chemicals in treating a ton of typical concentrate, so that the process would seem commercially feasible.

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## MAGNESITE.

By W. C. Phalen.

Raw Austrian magnesite contains iron in natural combination. That produced in the state of Washington has a much lower iron content, and before calcining 2¼ per cent. iron oxide in finely divided condition is added to the ground and screened magnesite and the mixture is then calcined at a high enough temperature to thoroughly sinter the iron oxide. The resulting product is as good as the Austrian in every way and has been exclusively used by one of the principal American makers of magnesite refractories since the middle of 1918, nearly 60,000 tons having been used and marketed. About 10 per cent. of the magnesite produced in this country is used to make magnesite flooring, or oxychloride cement, the manufacture of which began in the United States about 20 years ago in an experimental way and for the past 6 or 8 years has been commercially successful. When magnesite is calcined at a temperature of 1600° F., it produces caustic burned magnesite, which reacts with peculiar phenomena with a solution of magnesium chloride, producing, when in combination with fillers, a tough, compact mass known as oxychloride or sorel cement. The resultant composition has strength sufficient to make a compact, resilient, and sanitary flooring which has extraordinary strength to withstand blows and rough wear, is tough enough to prevent the formation of cracks, and is impervious enough to withstand puncture. Unlike Portland cement, it is possible to saw, cut, and insert screws into it. The product also possesses fire resistance, and heat insulation. It has, therefore, been found useful in monolithic floors, in stucco, and slabs, for insulation and pipe covering, for the decks of ships, the floors of freight and Pullman cars, hospitals, etc. Its cost is slightly in excess of foundation cement, but well within the cost of other permanent floorings, such as tile, etc.

## MINOR NOTES.

*Sulphur in Coal.*—A survey has been made of all present methods of removing sulphur from coal and its products. The substitution of Illinois coal for Eastern coke in the making of water gas in gas plants of the Middle West is greatly to be desired. The present gas-making equipment being designed for a non-volatile fuel, does not give as good results as may be expected on apparatus designed for bituminous coal. It appears that the design of such gas-making apparatus is largely empirical, and the Bureau will attempt to suggest a rational basis for the re-design of such apparatus for bituminous coal. The work, so far, appears very favorable.

*Dust in Copper Mines.*—The Bureau, in coöperation with the U. S. Public Health Service, has begun a study of dusts from the copper mines of Miami, Arizona. A volume of 19 cu. ft. of mine air is filtered through a glass tube containing 100 gm. of sugar, the tube being of such dimensions as to give a filtering column 1¾ in. high. The sugar is then dissolved in water and the recovered dust screened through a 280-mesh screen, which removes all particles larger than 50 microns in diameter. These are rejected, as particles of wet dust larger than 10 microns in diameter are considered harmless, since they do not lodge in the lungs. The dust is then graded into two portions, a non-injurious, consisting of particles between 12 and 50 microns in diameter, and an injurious, made up of particles smaller than 10 microns. Not enough samples have been analyzed as yet to give representative figures. The total dust will be determined in milligrams per cubic metre of air, the number of particles per cubic metre, the number of injurious particles per cubic metre, their weight in milligrams per cubic metre, and the weight of the dust over 10 microns diameter in mg. per cubic metre. Photomicrographs are also being made of characteristic dusts. The Bureau is also making a study of the concentration and nature of dusts in potteries, in coöperation with the Department of Labor. Samples are collected and the total weight of dust, total lead, and soluble lead determined. The soluble lead is determined by digesting the dust collected with a 0.25 per cent. solution of HCl., which takes into solution all the lead present as white or red lead, but does not act on the disilicate. The latter is considered harmless, as

it is not taken up by the human body. The investigation has, so far, shown that practically all the lead present in the glaze dusts is in the soluble form. A sample collected in a dipping room, while it was being swept, showed 47.9 mg. total dust, 8.7 mg. total lead and 8.7 mg. soluble lead. This represents very dusty conditions. Average figures per 100 cu. ft. of air collected in different rooms of potteries show from 2 to 100 mg. of total dust, and from 0.05 to 8 mg. of soluble lead.

Coal mine fatalities for the month of June showed a marked increase, compared with preceding months, due to the occurrence of an unusual number of explosions and other disasters.

All the new mine rescue cars of the Bureau have been accepted from the builders and put in use.

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**Photographic Records.** (*American Machinist*, vol. li, No. 4, July 24, 1919.)—While the camera and a photographer have become a part of the equipment of many shops, we are not as yet utilizing them to their capacity. They are too often confined to making photographs of completed machines for publicity purposes when there are many other uses where they would prove most valuable.

During the war nearly every machine-building shop was very active in the Liberty Loan campaigns, as well as the Red Cross and other drives. Attractive decorations were used in many cases, and much time and effort were spent to make these campaigns fully successful. Yet for the most part, the only records of these activities now in existence are in the memories of those who participated in them, making it impossible to comply with a governmental request for such photographs to be used in showing the activities of the machine-tool industry in the great war.

Memory plays us so many tricks that photographs of even commonplace things are often found valuable in later years. Even general photographs of various shop departments, either at stated intervals or after each alteration or rearrangement of machinery, may readily bring out that which otherwise escapes attention and perhaps prevent changes which would simply be a return to conditions found unsatisfactory.

Interesting machine set-ups, unusual tool fixtures and guages, photographs of machine failures and similar subjects are all likely to prove of value as time goes on.

These and similar photographs are particularly valuable in organizations having a publication which reaches the employees of the plant. Photographs can also be made extremely useful as an aid in instructing workers either in the shop or training school.

# THE FRANKLIN INSTITUTE.

## MEMBERSHIP NOTES.

### NECROLOGY.

**Mr. Andrew Carnegie** was born November 25, 1835, at Dunfermline, Scotland, and died at Lenox, Massachusetts, on August 11, 1919. He was brought to this country by his parents when twelve years of age, and settled at Allegheny City, Pennsylvania, in 1848. Two years later he became a telegraph messenger. He spent his spare time studying telegraphy, and was soon promoted to the position of operator. He then obtained a position with the Pennsylvania Railroad, and his advancement with this company was rapid.

About 1863 he organized the Keystone Bridge Company and soon after the Cyclops Mill. These were consolidated within a short time by the organization of the Union Iron Mills. Mr. Carnegie visited England in 1868 and while there investigated the Bessemer Process. On returning to this country he introduced the process in his mills.

After this he became principal owner of the Homestead and Edgar Thomson Steel Works and other large plants, as head of the firms Carnegie, Phipps & Company and Carnegie Brothers Company. In 1899 the interests of these various companies were consolidated under the name of the Carnegie Steel Company, which two years later was merged in the United States Steel Corporation, when Mr. Carnegie retired from business.

It would be impossible to give a detailed list of his benefactions and gifts, but the following are among the most notable: Carnegie Corporation of New York; Carnegie Foundation for the Advancement of Teachers; Carnegie Institute (Pittsburgh); Carnegie Institution of Washington; Carnegie Hero Funds; Endowment for International Peace; International Bureau of the American Republics.

During his lifetime he provided 2811 Free Public Library buildings, and contributed more than twenty millions of dollars to the colleges of the United States. He also made liberal contributions to organizations engaged in war work.

Mr. Carnegie was author of the following works: "An American Four-in-Hand in Britain," 1883; "Round the World," 1884; "Triumphant Democracy," 1886; "The Gospel of Wealth," 1900; "The Empire of Business," 1902; "The Life of James Watt," 1906, and "Problems of Today," 1909.

Mr. Carnegie became a member of The Franklin Institute in 1889.

**Mr. John Sterling Deans** was born at Chester, Pennsylvania, June 25, 1858, and died at Phoenixville, Pennsylvania, December 16, 1918. Mr. Deans' technical training was received at the Polytechnic College in Philadelphia. In 1879 he accepted a position with Clarke-Reeves & Company, which concern

later became the Phoenix Bridge Company. Thirteen years later Mr. Deans was made Chief Engineer, serving in this capacity until about three years ago, when he was appointed Vice-President and Consulting Engineer.

Remarkable developments in bridge construction occurred during Mr. Deans' career. Iron was gradually abandoned as the material for bridge building and replaced by steel. Mr. Deans was active not only as a designer and manufacturer, but also as a constructor of many notable structures: among these are the Ohio River bridges at Cincinnati and Louisville; Mississippi River bridges at Rock Island and Davenport; the cantilever bridge at Red Rock, Arizona; Kinzua and Pecos viaducts.

Mr. Deans was active in the development of the modern long span structure, and because of his unusual experience his counsel was frequently sought in connection with the designing of large steel bridges.

Mr. Deans became a member of The Franklin Institute on March 5, 1901.

**Allen Eugene Nichols** was born at Madison, Wisconsin, September 30, 1888, and died at Chicago, Illinois, on May 8, 1919. His early education was obtained in his native city, and in 1906 he entered the Civil Engineering Department of Purdue University, from which institution he graduated in 1910. Three years later the degree of Civil Engineer was conferred upon him by his *alma mater.*

On leaving college Mr. Nichols entered the employ of the Baltimore and Ohio Railroad Company. Some months later he was appointed an assistant to the Consulting Engineer for the State of Indiana, devoting his attention especially to the design of water works and sewage disposal plants. In April, 1911, he again became active in railroad work, and for more than a year served as Assistant Engineer on Track Elevation and Maintenance for the Chicago and Western Indiana Railroad Company. Later he became connected with a firm of consulting engineers, acting as assistant engineer of design and construction for sewage disposal and water supply plants. In February, 1914, Mr. Nichols entered the University of Pennsylvania as a special student, devoting his attention to the study of the chemistry of water. On completion of this work, in May, 1915, he was appointed one of the engineers for the Bureau of Waste Disposal of the city of Chicago, which position he held for nearly three years.

When the United States entered the war, Mr. Nichols joined the staff of the du Pont Engineering Company in the capacity of Engineer of Construction for a seventy million gallon water filtration plant for the Government powder factory, at Nashville, Tennessee. In February last, with his father and brother, he entered into the general engineering and contracting business. Mr. Nichols was a member of the American Society of Mechanical Engineers, the American Water Works Association and other kindred societies. He became a member of The Franklin Institute on March 14, 1917.

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## CORRESPONDENCE.

UNITED STATES DEPARTMENT OF AGRICULTURE.
Bureau of Plant Industry.

WASHINGTON, D. C., July 30, 1919.

*Dr. R. B. Owens,*
*Secretary, The Franklin Institute,*
*Philadelphia, Pa.*

DEAR DR. OWENS:

Your letter of July 28th informing me of the awarding of the Edward Longstreth Medal of Merit for 1919, has been received. The medal and certificate also came promptly.

I wish to express my appreciation to The Franklin Institute for the honor conferred and take this occasion to thank you for this.

Yours very sincerely,
J. J. SKINNER,
*Biochemist.*

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DEPARTMENT OF COMMERCE.
Bureau of Standards.

WASHINGTON, July 30, 1919.

Address reply to Bureau of Standards.

*Dr. R. B. Owens, Secretary,*
*The Franklin Institute,*
*Philadelphia, Pa.*

DEAR DR. OWENS:

Kindly bear to The Franklin Institute my heartiest thanks for the Edward Longstreth Medal and Certificate just received.

Yours very truly,
ENOCH KARRER.

Department of the Interior.
Bureau of Mines Experiment Station.

Golden, Colorado, August 2, 1919.

*Dr. R. B. Owens,*
*Secretary, The Franklin Institute,*
*Philadelphia, Pennsylvania.*

My Dear Doctor Owens:

I desire to acknowledge the receipt of the Edward Longstreth Medal, and also the certificate to accompany it.

I desire to thank the Committee on Science and the Arts and The Franklin Institute for the honor conferred upon me, and to express my appreciation of the award.

Sincerely yours,
R. B. Moore,
*Superintendent.*

---

Eastman Kodak Co.

Rochester, N. Y., August 4, 1919.

*Dr. R. B. Owens, Sec.,*
*Franklin Institute,*
*Philadelphia, Pa.*

Dear Sir:

I have received the Edward Longstreth Medal and Certificate recently awarded me jointly with Doctors Ives and Karrer.

I wish to take this occasion to thank the Institue and its Committee on Science and the Arts for the generous award. I am indeed pleased to know that the results of our joint labors on the Welsbach mantel have merited this recognition and it is certainly a most happy termination of the work.

Again thanking the Institute most hearily, I remain

Respectfully,
Edwin F. Kingsbury.

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## BOOK NOTICES.

One Thousand Technical Books. Compiled by Herbert L. Cowing. First Edition. 118 pages and index, 8vo, paper-bound. Washington, American Library Association, Library War Service, June, 1919.

The great increase of small libraries, whereof the chiefs and assistants are without technical training except in the specific field of library administration, has no doubt brought to the officers of the A. L. A. many requests for assistance in selections. Furthermore, the establishment of camp libraries with many patrons who had but limited technical training and desired more, compelled a selection of such works. With few exceptions the books chosen are of necessity of American origin, about half the list being credited to three New York City publishing houses. No two experts in any of the departments covered would be likely to agree throughout as to the selections, but in a

compilation of this kind, dogmatism cannot be avoided. The compiler may secure some assistance from experts, but must in the main be guided by the "inner light." The pamphlet represents a large amount of labor and will be of much aid along the lines for which it is prepared.

HENRY LEFFMANN.

LECTURE DEMONSTRATIONS IN PHYSICAL CHEMISTRY. By Henry S. van Klooster, Ph.D., Rensselaer Polytechnic Institute, 187 pages, illustrations, bibliography, index, 12mo. Easton, Pa., The Chemical Publishing Company, 1919. Price, $2.

This is a timely and interesting book. The literature of physical chemistry is immense and growing at a geometrical ratio, and while many illustrative experiments are detailed in the larger treatises, teachers of general chemistry, especially those who entered upon their work a generation or more ago, will find the collection of simple demonstrative methods very useful and convenient. Numerous illustrations aid in the construction and arrangement of apparatus. The author quotes Arrhenius to the effect that there are few departments of exact science in which so few lecture experiments are shown as in physical chemistry, and holds that this is due to the fact that so large a portion of the investigations is quantitative, while lecture experiments as a rule can only show qualitative changes. Doctor van Klooster also points out that many manuals of general chemistry spread the facts of physical chemistry over the whole of the descriptive text. Thus, adsorption is discussed in connection with charcoal, colloids with silicon, allotropy with oxygen. The book in hand is written in opposition to this plan. The classification is by type of phenomena, not by substance.

One of the most interesting chapters is that on Actino-chemistry. A number of very interesting experiments have been collected. The subject of flame, combustion and explosion is also interestingly treated. Another useful chapter is that on catalysis, but it is too brief.

The book is well printed, the type being that now so familiar to American chemists through the publications of the Easton firm. A few typographic errors have been noted, but are mere slips of the compositor and not misleading. The paper is not as good as it ought to be. It is to be hoped that the present edition will soon be exhausted and that the author will find time to prepare a second one on a much larger scale.

HENRY LEFFMANN.

# CURRENT TOPICS.

**Protection of Silvered Surfaces.** F. Kollmorgan. (*Journal of the Optical Society of America,* January–March, 1919, p. 16.)—At the commencement of the European war the importation of optical glass stopped completely, and at that time no glass suitable for optical instruments was being manufactured in this country. While it appeared probable that before long the glass industry of the United States would be in a position to turn out the ordinary kinds of optical glass, such as crown and flint, it was doubtful how long it would take before the considerable difficulties attending the manufacture of the more modern varieties of glass, such as the borosilicate crown and baryum crown, would be solved. Being engaged in the manufacture of periscopes for submarines, in which eyepiece reflectors of considerable size are used, the writer foresaw serious trouble unless some reflector could be developed which could take the place of the borosilicate prisms so far employed for that purpose. A plain glass mirror, silvered at the surface, of course, presented the easiest solution provided the surface could be protected efficiently against atmospheric influences. While looking up the subject of the possibility of such protection which, of course, must not, in any way, interfere with the optical efficiency of the mirror, it was found that as late as 1894, Mr. Izarn published in the *Comptes Rendus* a protective coating of bichromated gelatin which he had applied on a 33-centimetre telescope reflector at the Toulouse Observatory. This reflector withstood the influence of sulphuretted hydrogen for twenty-four hours without change. In 1909 Mr. A. Perot described also in *Comptes Rendus* a protective coating consisting of celluloid dissolved in amylacetate. Mr. Louis Bell in the *Electrical World,* 1913, mentions the employment of a commercial lacquer sold under the name of Lastina Lacquer for the same purpose with very good results. It appears that a two-foot parabolic reflector used at the Harvard Observatory protected in this manner, lost only 4 per cent. of its original light transmission through the lacquering, and after three months service still retained 70 per cent. of its original light transmission.

Both Mr. Perot's and Mr. Bell's papers, however, state that the lacquer must be used in a very thin layer and will show interference colors. The first experiments made by the writer produced an efficient protection, but it was found that the interference colors showed plainly when the eyepiece was used on a periscope and this phenomenon had to be overcome. When the coating of lacquer was sufficiently thick to show no interference colors the lacquer dried sometimes in waves and streaks, and sometimes with a crinkly sur-

face seriously damaging the definition of the mirror, and it occurred to the writer that this appearance might be avoided by centrifuging the mirror during the drying so that the surface would be kept under an even tension until dry. An experiment along these lines proved very satisfactory and mirrors protected in this manner have been used since in a large number of periscopes with very good results. Even after a year's use the mirrors have shown no appreciable decrease in efficiency and no appearance of tarnishing whatever. The reflecting power of these mirrors is greater than that of a prism, for in some of our periscopes we have employed a mirror at the top for the high power and a prism for the low power and the increase in light transmission from low to high power has been quite noticeable. Owing to the rush of war work, it has unfortunately been impossible to make exact measurements of the light transmission.

The protection given by the coating of lacquer, is, however, a very slight one against mechanical damage, as the lacquer is very soft and will scratch at the slightest touch. If dust should settle on the mirror it must be removed by means of a very fine camel's-hair brush; a soft piece of chamois leather may be employed if care is taken that it is absolutely free from grit or dust. Attempts to harden the lacquer by baking have not proved successful. Various other lacquers and varnishes that were tried did not give as good optical results as the Lastina lacquer. Mr. Bell's paper suggests that lacquer should be thinned down in proportion of one part lacquer to six parts commercial thinner. We use one part lacquer and two parts thinner with our method.

**Electrical Distribution in Mines.** E. STECK. (*Coal Age*, vol. xvi, No. 1, July 3, 1919.)—The bituminous mines in the central states have a general practice of connecting the entire electrical distribution system underground to a circuit breaker on the surface. This practice has a number of shortcomings. If the circuit breaker trips all the locomotives, cutting machines and other motors are stopped. As soon as the breaker is put in all the motors are thrown on the line, creating a heavy overload on the power-plant equipment. All the machinery below is idle while the circuit breakers are out.

When heavy grounds occur there is no indication of their location. The entire mine is idle until the trouble is found and that section in which the short has occurred is cut off, or the trouble remedied.

By the use of circuit breakers underground trouble can be located much quicker. Only a small portion of the mine will be idle at such times and the starting over-load on the plant will be greatly reduced. Take, for example, a mine having two main entries: A switchboard panel can be placed on the bottom with two circuit breakers and switches, each controlling one-half of the mine. The lights on the bottom can be connected in behind

the circuit breaker so that no matter which breaker trips the lights will still be in service. The circuit breakers should be of the switchboard type. This makes each half of the mine independent of the other. This scheme can be further carried out by the location of railway-type circuit breakers at convenient places back in the mine. With such a layout in case of trouble a small part of the mine only is effected and the difficulty quickly located, as it must be behind the circuit breaker which has opened.

The small breakers pay for themselves in a short time because of the shorter shutdowns and the lower number of locomotives and machines affected. The wear and tear for this reason is not so great on the power-plant equipment. If power is purchased, especially where the maximum demand charged is based on short-time peaks, a decided saving in the power bill can be made because all of the equipment cannot then be thrown on the line at once after the main circuit breaker is closed on top.

**Gas-masks for Protection in Industries.** (*Journal Industrial and Engineering Chemistry.*)—The Gas-mask Research Division of the Chemical Warfare Service has called attention to the value of the army gas-mask in many industries in which offensive or poisonous gases are produced. As is well known, the United States chemists brought the gas-mask to a high degree of efficiency. The principal contents were charcoal and soda-lime in granules ranging between 8 and 14 mesh. This filling stopped chlorine phosgene, chlorpicrin, nitrogen oxides and some other gases; for gasoline, benzine, carbon disulfide, carbon tetrachloride, cyanogen bromide, and some other vapors not acted on by soda-lime, the charcoal filling alone will suffice. For acid vapors, and some acid anhydrides (*e.g., sulphur dioxide*) soda-lime alone was used.

When smoke particles, such as the hydrolysis products of stannic chloride, or solid particles, as arsenic trioxide, are encountered, the canister should contain at least two cotton wadding pads or other filter material.

Ammonia is not completely absorbed by the standard filling. For this purpose copper sulphate on pumice is recommended.

In considering the use of gas-masks for protection against various gases it must be emphasized that they should never be used in atmospheres containing less than 12 per cent. oxygen by volume. In such atmospheres an air helmet or a self-contained breathing apparatus containing an oxygen supply must be used. Neither does the army gas-mask afford complete protection against very high concentration of toxic or irritating gases, such as may be found in closed tanks or towers containing volatile liquids or in small closed rooms where a considerable quantity of gas has been suddenly released. In general, the gas-mask is limited to concentrations not exceeding 1 to 5 per cent., depend-

ing on the kind of gas, the absorbent used, and the size of the canister.

The standard canister containing filter pads gives good protection against smoke from wood, rags, tar, sulphur, and other combustibles. Tests have been made in which men wearing standard army masks remained in dense smoke from burning wood and wet straw for a period of twenty minutes without discomfort. Care, however, must be observed that such combustion smoke contains no appreciable quantities of carbon monoxide, for which the mask provides no protection, and which would not be detected by the wearer before being overcome. For this reason the standard army gas-mask with charcoal and soda-lime canister containing filter pads should be used with some caution by firemen in entering burning buildings; in exceptional cases, dangerous quantities of carbon monoxide may be present.

The army mask has been used successfully in fighting forest fires. It can probably be used safely in similar smoke occurring in the open air, or for a very short period of time in buildings where the smoke is diluted by air. H. L.

**Gluing Wood Coated with Varnish or Shellac.** (*Technical Notes,* Forest Products Laboratory, Madison, Wisconsin.)—Glue joints between wood surfaces which have been coated with shellac or varnish have low or very erratic strength. This has been thoroughly demonstrated by a recent test at Forest Products Laboratory, Madison, Wis. Sixty pairs of test blocks were prepared in which one or both wood surfaces were varnished or shellacked and were joined with either casein or animal glue. A great many of these blocks fell apart before testing and all which held together long enough to be tested sheared apart in the glue joint and not in the wood.

The highest strength value obtained was 1712 pounds per square inch, which is low for casein glue. The other values were 1000 pounds per square inch or less. It is evident, therefore, that all shellac or varnish should be carefully cleaned from wood which is to be glued, if high strength is desired.

A few blocks were joined using shellac as a glue over surfaces previously coated with shellac. The maximum shear strength obtained was 1425 pounds, the minimum 450 pounds, and the average 758 pounds per square inch. These values are low and do not indicate that shellac has gluing properties which compare favorably with casein or animal glue.

**"American Storax" from the Red Gum Tree.** (*Technical Notes,* Forest Products Laboratory, Madison, Wisconsin.)—A gum which is in demand by the manufacturers of perfumes, tobacco, adhesives, and pharmaceutical preparations, is produced by the red gum tree (*Liquidamber styraciflua*) of the south, though few owners

of this tree apparently are yet aware that the gum has any commercial value. The properties and composition of this "sweet gum," as it is called, are similar to those of oriental storax, obtained from a tree (*Liquidamber orientalis*) which grows in Asia Minor. Cinnamic acid and cinnamic alcohol are two of its valuable components.

Because the war curtailed the supply of the imported product, the U. S. Forest Products Laboratory this season undertook some coöperative experiments to develop methods of gathering "sweet gum" or "American storax." Although the yield of gum from each tree is not large, a price of $2 or more a pound has made its collection attractive to many individual operators and a considerable quantity has been put on the market.

The laboratory experiments will be completed in November, and it is hoped that they will provide some cost data which will indicate to what extent "American storax" can profitably compete with the foreign product when normal conditions return.

**Detection of Dulcin and Saccharin by Optical Methods.** A. ABRAHAM. (*Mem. Acad. Roy. d. Sciences de Liége*, vol. x, p. 4.)—Dulcin and saccharin are liable to be used in many beverages as substitutes for sugar. They are usually detected by color tests, but the author of this paper gives an account of their detection by the microscopic examination of the crystals from an ether-solution. These optical methods are becoming of increasing importance. They depend on the use of modified light, especially polarization. Very small crystals can be identified accurately. The method, as is well known, has been long applied in mineralogy in the examinations of rock-sections. The microscopic equipment is complicated and expensive. The United States Department of Agriculture is conducting special researches along this line, especially in connection with the detection of the alkaloids. H. L.

**The Production of Large Perfect Crystals.** R. W. MOORE. (*J. Am. Chem. Soc.*, vol. xli, p. 1060, 1919.)—After briefly reviewing the literature of the subject, describes a method by which very large and perfect crystals can be obtained from solution. It is well known that many fine crystals are found in nature, but these are usually so involved in the matrix as to prevent separation without injury and are often unequally developed in some planes. Moore required some perfect crystals of sodium-potassium tartrate and searched through several tons of the salt finding but little material. After examining the published methods, he devised a plan by which a saturated solution of the substance is made at a temperature between 35° and 40° C. This is heated a few degrees higher and then filtered. The temperature must be kept slightly above the saturation temperature. Small crystals of the salt, termed "seed-crystals," are placed in a jar, the solution

poured in the jar covered and placed in a large water-bath which is at a temperature of about 0.5° above the saturation temperature of the solution. The temperature is allowed to fall practically to the saturation temperature of the solution. By means of a sensitive thermostat the temperature is allowed to fall about 0.1° per day until the crystals have increased notably in size, and have formed perfect crystals. This usually takes a short time. The temperature is then allowed to fall 0.2° per day. When the crystals are nearly an inch long the rate of cooling is increased to about 0.4°, and when they are well over 1 inch to 0.6° per day. The thermostat setting is changed twice each day, morning and evening. When the solution has cooled to room temperature the crystals are taken out and wiped with a soft dry cloth. A photograph is given with the article showing some very fine crystals of sodium potassium tartrate produced by this method. The process is slow—to produce perfect crystals three inches long requires about one month. They are, however, well worth the trouble. Success depends, of course, largely on steady, slow cooling. Only when a condition of slight supersaturation is maintained does the crystal grow perfectly clear.

H. L.

**The Insulating Properties of Erinoid.**—Erinoid is a product of the action of formaldehyde on milk proteins. Casein products as substitutes for ivory, bone and similar substances have long been known. The best methods for their production were due to Swiss and German chemists. The war deprived British markets of the supplies, and British chemists took up the matter with the result of obtaining an excellent material to which the above name was given. Its insulating properties have been subjected to a careful examination by R. G. Allen, B.Sc., whose methods and results have been set forth in the *Scientific Proceedings of the Royal Dublin Society* (vol. xv, p. 331, 1919). The summary of experiments is as follows:

1. When dry, erinoid is a good insulator of fairly constant insulation resistance. It is slightly hygroscopic, but not so much as fibre.
2. Erinoid does not absorb water when in direct contact with it so readily and to such an extent as red fibre, neither is it so retentive of the water absorbed as the latter.
3. When its surface is not machined its resistance greatly depends upon the value of the applied voltage, unless water electrodes are used. This dependence is very slight in the case of unmachined fibre, whether mercury or water electrodes are used. In the case of machined erinoid the resistance is almost independent of the voltage.
4. It is practically free from dielectric absorption, but the latter is appreciable in the red fibre.
5. The relation pointed out by Rasch and Hinrichsen between temperature and resistance is true for erinoid and fibre.

6. Of the varieties of erinoid tested, red is the most absorbent of water and generally of the lowest resistance.

7. Erinoid of blonde color has a considerably larger resistance than the other varieties tested: probably due to greater skin or contact resistance.[1]

8. The specific resistance of erinoid diminishes with the thickness of the sample.

9. The break-down voltage of erinoid and fibre is practically the same. H. L.

**Largest Aircraft Engine.** (*Power Plant Engineering,* vol. xxiii, No. 14, p. 634, July 15, 1919.)—Marked progress is being made in the design of internal combustion engines to keep pace with the ever-increasing size of aircraft. Undoubtedly the largest aircraft engine which has been developed, to date, is the 850-h.p. Duesenberg motor. It has 16 cylinders, 6 by 7½ in., in two rows of eight each set in "V" form at an angle of 45 deg. With gear drive, the weight is 1575 lbs.; without gear drive, 1390 lbs. On direct drive, the speed is 1500–1600 r.p.m.; and with gear drive, the engine speed is 1800; propeller 1200–1350 r.p.m. Based on the lower rating and direct drive, the weight of the engine is 1.63 lbs. per h.p., a remarkably low figure for an engine of this type.

Three valves are provided on each cylinder, a 2⅝-in. inlet valve and two exhaust valves, each 2 in. in diameter. The intake valve is located above the exhaust valves, and by this plan the exhaust valves are cooled by the incoming mixture and the mixture itself is slightly warmed. Valves are operated by means of long rocker arms from a single cam shaft. This cam shaft is $^{13}/_{16}$ in. in diameter with ¾-in. hole, and is 70⅝ in. long. The 48 cams are forged integral with the shaft. Two short exhaust pipes per cylinder of 2-in o.d. tubing are provided. Gas is provided by four carburetors, and ignition by means of two magnetos. The propeller shaft is geared to the crank-shaft in the ratio of 2 to 3, running at 1200 r.p.m.

Cam-shaft and rocker-arm actuating mechanism are enclosed in a dust-proof housing, and to this mechanism oil is fed under pressure. Rocker-arm bearings are of special bronze, and the cam-shaft bearings are of aluminum with babbit liners. Connecting rods are of the straight and straddle type, fitted with bearings of special bronze. Pistons are of special aluminum alloy, and each has but one ring. They are heavily ribbed inside, 5¼ in. deep and have 1½ in. piston pins.

Cylinders are made from pierced forgings of chrome-nickel steel. The cylinder head is composed of steel stampings which are first welded together, then screwed into the cylinder, and afterward welded to the cylinder. The water jacket of stamped sheet steel is

[1] This was definitely shown, later, by testing machined blonde erinoid and finding it had practically the same resistance as black and red erinoid.

welded in position. The crank-shaft is $2\frac{7}{8}$ in. in diameter and has a main bearing between every other pair of crank-pins. Oil is forced through the shaft under heavy pressure direct to all bearings, including those of the connecting rod.

Of the barrel type, with dry sump oil pan, the crank-case is fitted with strainers at each end so that the oil will flow to the pump regardless of the angle of flight.

**Industrial Uses of Soya Bean Oil.**—The soya bean is the seed of a plant native to northeastern Asia. Although practically unknown in this country before 1908, very large shipments have been made to Europe and America in recent years. The crude oil obtained by expression may be purified by sodium hydroxide as in the case of cottonseed oil, and then constitutes a valuable food oil. In a cruder form it is a drying oil, and owing to this quality has become a staple of the paint trade. Henry A. Gardner, Director of the Scientific Section of the Paint Manufacturers' Association of the United States, discusses the matter in Circular 67 of the Educational Bureau of that association. Soya oil cannot be used wholly in place of linseed oil on account of the feebler drying powers of the former, but may be used to the extent of about 50 per cent. In such large admixture, driers must be added. Gardner made a study of proposed driers, and finds that when properly selected the drying power of the soya oil is very high. Linoleates are the best salts. Cobalt and manganese salts have a tendency to produce hard films; lead and zinc salts produce somewhat elastic films. A combination of the two sets will, therefore, be best. The following formulas are given:

| | |
|---|---|
| Manganese linoleate containing ..... | 0.03 per cent of Mn. |
| Lead linoleate containing ........... | 0.20 per cent. of Pb. |
| Cobalt linoleate containing ......... | 0.01 per cent. of Co. |

and

| | |
|---|---|
| Lead linoleate containing .......... | 0.20 per cent. of Pb. |
| Cobalt linoleate containing ......... | 0.02 per cent. of Co. |

The cake and meal after the extraction of the oil are suitable as stock-food and fertilizer.

As the plant is a native of a region in which the climate conditions closely resemble those of some portions of the United States, the cultivation of it in this country will probably be successful. Especially in those sections of the South in which the boll-weevil has exterminated cotton-raising, the cultivation of this plant may be useful, as the cotton-seed mills are well adapted for the crushing of the soya bean. Crude soya oil is also useful in the manufacture of soap. H. L.

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## OPTICS OF THE AIR.*


BY

W. J. HUMPHREYS.

Professor of Meteorological Physics, United States Weather Bureau.


### INTRODUCTION—CLASSIFICATION.

Many curious and beautiful phenomena, of which the mirage, the rainbow, the halo, the azured sky, and the twilight glow, are some of the more conspicuous, are due to the optical properties of the air and the foreign substances suspended in or falling through it. All, or nearly all, of them have been the objects of innumerable observations and many careful studies, the results of which, fortunately, have been summarized and discussed by various authors. The most extensive discussion, however, of this subject is by Pernter and Exner, whose work, "Meteorologische Optik," therefore, will be largely, but by no means exclusively, drawn upon for the material of this section.

When one's chief or only purpose in discussing the optics of the air is to describe the phenomena seen, it is convenient to divide them into such general classes as mirages, rainbows, halos, coronas, etc. For explanatory purposes it is more convenient, perhaps, to group them according to (*a*) their objective or material causes, namely: atmosphere, raindrops, water droplets, ice crystals, etc.; or (*b*) their physical causes, such as reflection, refraction, diffraction, etc.


* Continued from page 509, Vol. 186, October, 1918.

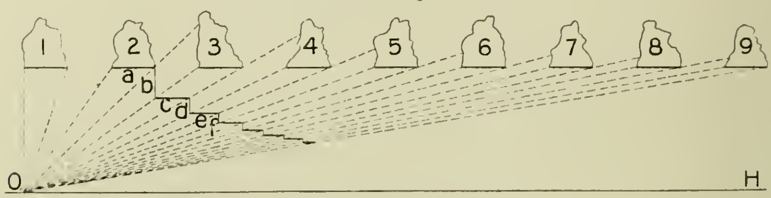
Each of the above classifications has its advantages and disadvantages. On the whole, however, the division according to physical causes seems best suited to the needs of an explanatory discussion and therefore is here adopted.

## Chapter I.

### PERSPECTIVE PHENOMENA.

*Apparent Stair-step Ascent of Clouds.*—The stair-step appearance of the echelon cloud (Fig. 103) is, perhaps, the simplest sky phenomenon due to perspective. The exact manner by which the stair-step or terrace illusion is brought about is shown by Fig. 123, in which $O$ is the position of the observer, $H$ his horizon, 1, 2, 3, etc., evenly spaced flat-bottomed cumuli of the same

Fig. 123.




Cloud echelon effect.

base elevation—flat-bottomed and of constant level because of the approximately uniform horizontal distribution of moisture.

Since the clouds are at a higher level than the observer, each successive cumulus, as the distance increases, is seen at a lower angle than its predecessor; and the dark bases of any two adjacent clouds appear to be connected with each other by the lighter side of the farther one. Besides, their general resemblance to stair-steps often leads one into the error of "seeing" the connection between any two adjacent bases to be at right angles to both. That is, starting with base *a*, the light side of cloud 3 appears as a vertical surface at *b*, and its base as a dark horizontal surface at *c*; the side and base of cloud 4 appear as the next vertical and horizontal surfaces, *d* and *e*, respectively, and so on for the other clouds; the whole effect merging into the appearance of a great stairway, consisting of the horizontal treads, *a*, *c*, *e*, etc., connected by the seemingly vertical risers, *b*, *d*, *f*, etc.

*Apparent Arching of Cloud Bands.*—Occasionally a narrow

cloud band is seen to stretch almost, if not entirely, from horizon to horizon, but although its course is practically horizontal and its direction often nearly straight, it usually appears arched. If even the nearest portion of the cloud still is far away, the apparent arching is slight. On the other hand, when the cloud is near the arching is great. The apparent curve is neither circular nor elliptical, but resembles rather a conchoid whose origin is at the observer and whose asymptote is his horizon.

The angle of elevation at which different segments of the cloud are seen clearly varies from a minimum for the more distant portions to a maximum for the nearest. Hence, the phenomenon in question, the apparent arching of the band along its nearest portions, is only an optical illusion, due entirely to the projection of the cloud (above the observer's level) onto the sky.

When several such bands or streaks occur in parallel, they appear to start from a common point at or beyond the horizon, to terminate, if long enough, in a similar opposite point, and progressively to arch and spread apart as they approach the observer's zenith. They thus form the perspective effect often called " Noah's Ark " or polar bands.

*Apparent Divergence and Convergence of Crepuscular Rays (Sunbeams)*.—Everyone is familiar with the beautiful phenomenon of the " sun drawing water "—sunbeams that, finding their way through rifts in the clouds, are rendered luminous by the dust in their courses. Equally familiar and equally beautiful are also those streaks and bands of pearly lights (where the lower atmosphere is illuminated) and azure shadows (where only the upper atmosphere is illuminated) that often at twilight and occasionally at dawn radiate far out from the region of the sun, and at times even converge towards the opposite point of the horizon. These, too, are only beams of sunlight and shadow caused by broken clouds or irregular horizon.

All such crepuscular rays, whether their common origin, the sun, be below or above the horizon, seem first to diverge, while the few that cross the sky appear also to arch on the way and finally to converge towards the antisolar point.

Here, again, the facts are not as they seem, for the rays, all coming, as they do, from the sun, some 93,000,000 miles away, necessarily are practically parallel. Their apparent divergence, convergence, and arching are all illusions due to perspective, just

as are the apparent divergence, convergence, and arching of the rails on a long straight track.

*Apparent Divergence of Auroral Streamers.*—Anyone at all familiar with the appearance of auroral streamers will recall that at most localities they seem to radiate from some place far below the horizon. In reality they do diverge (or converge, if one prefers) slightly since they follow, approximately, the terrestrial lines of magnetic force. Indeed, their rate of convergence is about the same, on the average, as that of the geographic meridians at the same latitudes, and therefore far less than one would infer from their apparent courses. That is, their seeming rapid convergence is only another illusion due to perspective, just as is the apparent divergence of the crepuscular rays, as above explained.

*Apparent Shape (Flat Vault) of the Sky.*—To everyone the sky looks like a great blue dome, low and flattish, whose circular rim rests on the horizon and whose apex is directly overhead. So flat, indeed, does this dome appear to be that points on it estimated to lie half-way between the rim and apex generally have an elevation of but little more than 20°, instead of 45°, as they would if it seemed spherical.

That the rim of the sky dome should appear circular is obvious enough. It is simply because the horizon, where land and sky come together, itself is circular, except when conspicuously broken by hills or mountains.

To understand the other and more important feature, that is, why the dome looks so flat, consider (1) a sky filled from horizon to horizon with high cirrus clouds. These seem nearest overhead for the simple reason that that is just where they are nearest. As the horizon is approached, the clouds merge, through perspective, into a uniform gray cover that appears to rest on the land at the limit of vision, whether this limit be fixed by the curvature of the earth or by haze, and the whole cloud canopy may seem arched just as and for the same reason that cloud streaks and crepuscular rays seem arched, as above explained. But (2) even a thin cirro-stratus veil whose parts are well-nigh indistinguishable produces a similar effect, the nearest portions appearing nearest, largely because they are the most clearly seen. Similarly, when there are no clouds the sky overhead also appears nearest because it is clearest; and that unconscious inference,

based on endless experience, is correct—it is clearest because nearest. As the eye approaches the horizon, the increasing haze produces the impression of greater distance; and this impression is entirely correct, for the blue sky seen in any such direction is farther away than the sky overhead. In short, the spring of a cloudless sky dome is "seen" to rest on the distant horizon and its ceiling to come closer and closer, in proportion to increasing clearness, as the zenith is approached. The shape, then, of this dome should not always appear the same, and it does not—not the same on a clear night, for instance, as on a clear day.

Impressions, therefore, of the "shape" of the sky are, perhaps, not so erroneous as sometimes they are said to be. Indeed, they usually conform surprisingly well to the actual facts.

*Change, with Elevation, of Apparent Size of Sun and Moon.*—One of the most familiar, as also one of the most puzzling, of optical illusions is the change between the apparent sizes of the full moon, say, or of the sun, at rising or setting, and at or near culmination. It is, however, only a phenomenon of perspective.

Since the solid angle subtended at any place on the earth by the moon, as also that subtended by the sun, is sensibly constant throughout its course from rising to setting, it follows that its projection, and, therefore, its apparent size, must be relatively large, or small, as the place of projection (sky dome) is comparatively far away or nearby. But, as already explained, the sky dome, against which all celestial objects are projected and along which they therefore appear to move, seems to be farther away, and is farther away, near the horizon than at places of considerable elevation. Hence the moon and the sun must look much larger when near the horizon than when far up in the heavens, and the fact that they do so look, is, as stated, merely a phenomenon of perspective.

The familiar fact that the moon appears of one size to one person and a different size to another clearly is also due to perspective. The one who judges it large imagines his comparison object to be at a greater distance than does the one who judges it small. Why two people, however, should differ so widely in their reference or comparison distances, as obviously they often do, is by no means clear.

*Change, with Elevation, of Apparent Distance Between Neighboring Stars.*—The generally recognized fact that the dis-

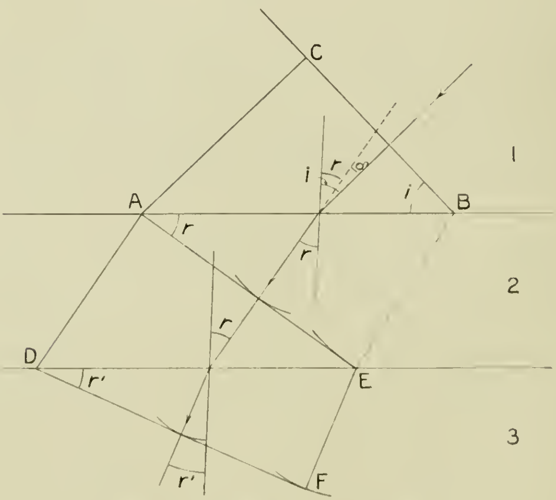
tance between neighboring stars appears much greater when they are near the horizon than when well up is also a phenomenon of perspective. Its explanation is identical with that of the change, under similar circumstances, of the apparent diameter of the moon, and therefore need not be given in further detail.

## Chapter II.

### REFRACTION PHENOMENA: ATMOSPHERIC REFRACTION

*Astronomical Refraction.*—It is well known that because of astronomical refraction the zenith distance of a star, or other celestial object, is greater than it seems, except when zero, to an extent that increases with that distance. To understand this im-

Fig. 124.




Refraction of light on change of media.

portant phenomenon, it is necessary to recall two experimental facts: (*a*) that in any homogeneous medium light travels in sensibly straight lines, and (*b*) that its velocity (velocity pertaining to any given wave frequency) differs from medium to medium.

Let, then, the parallel lines *AB* and *DE* (Fig. 124) be the intersections of the boundaries between three homogeneous media, 1, 2, 3, by a plane normal thereto and to the wave front, *BC*. Let the velocities in these media of a given monochromatic light be

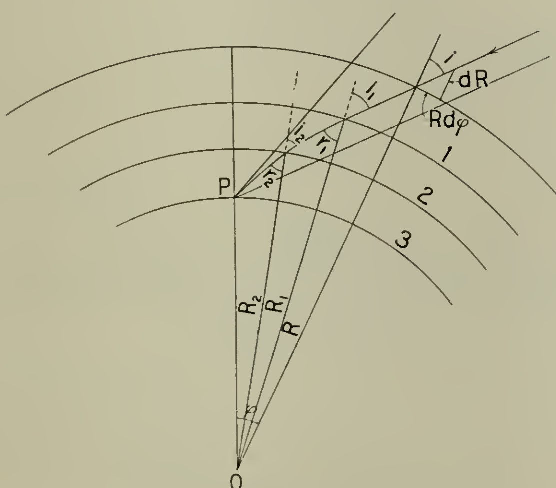
$v_1$, $v_2$, and $v_3$, respectively. Hence, when the light disturbance at $C$ has travelled the distance $CA$ in the first medium, that at $B$ will have gone the distance $BE$ in the second, where $CA/BE = v_1/v_2$, and $AE$ will be the new wave front. Similarly, $DF$ will be the wave front in the third medium, and so on for any additional media that may be traversed.

If $i$ is the angle between the normal to the interface, $AB$, and the direction of the light, both in medium 1, and $r$ the corresponding angle in medium 2, then, as is obvious from the figure,

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2}, \text{ or } \sin i = \frac{v_1}{v_2} \sin r.$$

Similarly, $\sin r = \dfrac{v_2}{v_3} \sin r'$. Hence, $\sin i = \dfrac{v_1}{v_3} \sin r'$. That is, the total change in direction of the light depends solely on its velocities in the first and final media, respectively, and the initial angle of incidence. The optical densities of the intermediate

FIG. 125.




Path of light through the atmosphere.

layers may abruptly change by large amounts, as indicated, and thus cause the light to follow a perceptibly broken course, as from air to water, for instance; or they may change so gradually that the path is a smooth curve, even to the closest observation.

Since the ratio of the velocity of light in space to its velocity in any given gas, or definite mixture of gases (the refractive index of that medium), increases directly with density, it follows that all rays of light that cross the atmospheric shell, except those that enter it normally, must follow continuously curved paths, somewhat as shown to an exaggerated extent in Fig. 125.

To determine the shape of such a curve through the atmosphere, let $\phi$ (Fig. 125) be the angle between the radii from the centre of the earth at the place of observation and any other point along the course of a refracted ray.

As before,

$$\mu_2 \sin r_1 = \mu_1 \sin i_1$$

in which $\mu_1$ and $\mu_2$ are the refractive indices (with reference to space) of media, or layers, 1 and 2, respectively, $i_1$ the angle of incidence and $r_1$ the angle of refraction at the interface between these media or layers. But, corresponding to the radii $R_1$ and $R_2$,

$$\frac{\sin i_2}{\sin r_1} = \frac{R_1}{R_2}$$

Hence,

$$R_1 \mu_1 \sin i_1 = R_2 \mu_2 \sin i_2 ,$$

or, in general,

$$R \mu \sin i = C, \text{ a constant.}$$

Further,

$$\frac{dR}{Rd\phi} = \cot i.$$

But $\cot i =$

$$\frac{\cos i}{\sin i} = \sqrt{\frac{1 - \sin^2 i}{\sin^2 i}} = \sqrt{\frac{\mu^2 R^2}{C^2} - 1}$$

Hence,

$$\frac{dR}{d\phi} = R \sqrt{\frac{\mu^2 R^2}{C^2} - 1},$$

and

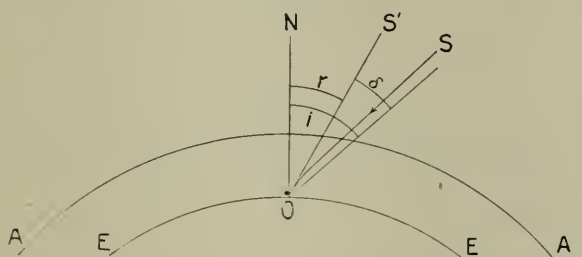
$$\phi = \int_{R_0}^{R} \frac{dR}{R\sqrt{\frac{\mu^2 R^2}{C^2} - 1}}$$

Clearly, then, the value of $\phi$ corresponding to a definite value of $R$, or the value of $R$ appropriate to a definite value of $\phi$, depends upon the relation of $\mu$ to $R$, or, very nearly, the relation of

the density of the atmosphere at any point to the altitude of that point. Hence, refraction curves may be drawn for different angles of incidence, or, if preferred, for different apparent altitudes, according to any assumed distribution of atmospheric density—a distribution fairly well known.

The approximate value of astronomical refraction, that is, its value generally to within one second of arc, through all zenith distances up to at least 60°, may easily be obtained as follows: Assume the atmosphere to be flat, as it nearly is, over the restricted area through which stars may be seen whose zenith distances are within 60°, or thereabouts. Let $O$ (Fig. 126) be the position of the observer, $S$ the true position of a star and $S'$ its apparent position.

FIG. 126.




Approximate astronomical refraction.

As explained above,

$$\sin i = \mu \sin r$$

in which $\mu$ is the refractive index of the air at the point of observation, $i$ the actual and $r$ the apparent zenith distance. But

$$i = r + \delta$$

in which $\delta$ is the angle of deviation.

Hence,

$$\sin (r + \delta) = \sin r \cos \delta + \cos r \sin \delta = \mu \sin r$$

When the angle of incidence is 60°, or less, $\delta$ is always very small, and

$$\sin \delta = (\mu - 1) \tan r, \text{ nearly.}$$

Expressed in seconds of arc this gives

$$\delta'' = 206265'' (\mu - 1) \tan r$$

in which the numerical coefficient is the approximate number of seconds in a radian.

For dry air at 0° C. and 760 mm. pressure, the average value of $\mu$ is about 1.000293.

Hence, also

$$\delta'' = 60''.4 \tan r.$$

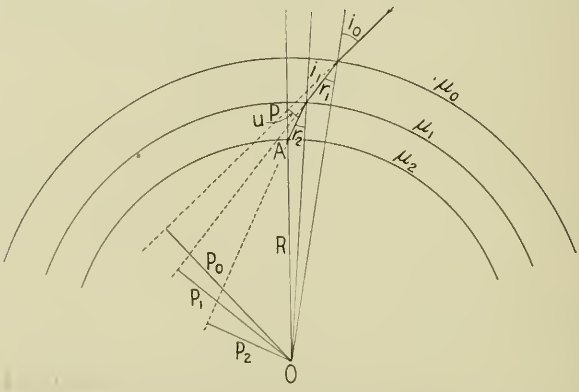
But for gases $\mu - 1 = K\rho$, very closely, in which $K$ is a constant and $\rho$ the density.

Hence, finally,

$$\delta'' = \frac{21''.7\ B}{T} \tan r,$$

in which $B$ is the height of the barometer in millimetres, and $T$ the absolute temperature in degrees C.

FIG. 127.




Astronomical refraction (Lord Rayleigh).

As a matter of fact, the atmospheric shell is not plane, even over small areas, but slightly curved, and therefore the complete formula for astronomical refraction, such as is needed for the construction of tables to be used in the most accurate measurements of star positions, is rather complicated. Probably the briefest and simplest derivation of a formula adequate for all zenith distances to at least 75° is due to Lord Raleigh,[107] and is essentially as follows:

Let $p_0$, $p_1$, $p_2$, etc., be the normals from the centre of the earth onto the tangents of a ray path through the atmosphere at the

[107] *Phil. Mag.*, 36, p. 141, 1893.

points where the refractive indices are $\mu_0$, $\mu_1$, $\mu_2$, etc., respectively. Let $i_0$, $i_1$, $i_2$, etc., be the angles of incidence, and $r_1$, $r_2$, etc., the corresponding angles of refraction. Then (see Fig. 127),

$$\frac{\mu_0}{\mu_1} = \frac{\sin r_1}{\sin i_0} = \frac{p_1}{p_0},$$

$$\frac{\mu_1}{\mu_2} = \frac{\sin r_2}{\sin i_1} = \frac{p_2}{p_1}, \text{ etc.}$$

Hence,

$$\mu\, p = \text{constant.}$$

Let the tangent to the ray path, where it enters the atmosphere, meet the vertical at the distance, $C$, above the point of observation, $A$; let $\mu_s$ be the refractive index at $A$; $\theta$ the apparent zenith distance; $\delta\theta$ the total refraction; and $R$ the radius of the earth. Then, since the refractive index of space is 1,

$$\mu_s\, p_2 = p_0, \text{ or } \mu_s R \sin\theta = (R + C)\sin(\theta + \delta\theta) \;.\;.\;.\;.\;. \quad \text{(A)}$$

Obviously, the refraction, $\delta\theta$, could be determined from this equation directly if the value of $C$ were known. But

$$C = \frac{u}{\sin\theta} \;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;. \quad \text{(B)}$$

in which $u$, the total linear deviation of the ray, may be substituted by known terms. Hence, $C$ and, therefore, $\delta\theta$ are determinable.

To determine $u$, let $\alpha$ be the angle which the ray makes with the direction of most rapid increase of index of refraction (at the surface $\alpha$ equals $\theta$); $z$ the vertical coördinate; and $v$ the velocity of light. Now consider a wave front moving through the atmosphere in any direction except vertical. The portion in the higher or thinner air will move faster than that in the denser air and the path will be curved. If $\rho$ is the radius of curvature and $d\rho$ is regarded as positive when measured towards the centre, then, as is obvious from Fig. 128,

$$\frac{d\rho}{\rho} = -\frac{dv}{v}$$

Also, since the refractive index, $\mu$, is inversely proportional to the velocity, $v$,

$$\frac{d\rho}{\rho} = \frac{d\mu}{\mu}$$

Hence, calling the path $s$, and since

$$\frac{d\mu}{d\rho} = \frac{d\mu}{dz}\sin\alpha\,,$$

$$\frac{1}{\rho} = \frac{d\log\mu}{d\rho} = \frac{d\log\mu}{dz}\sin\alpha = \frac{d\log\mu}{ds}\tan\alpha = \frac{d^2u}{ds^2}$$

To a close approximation,

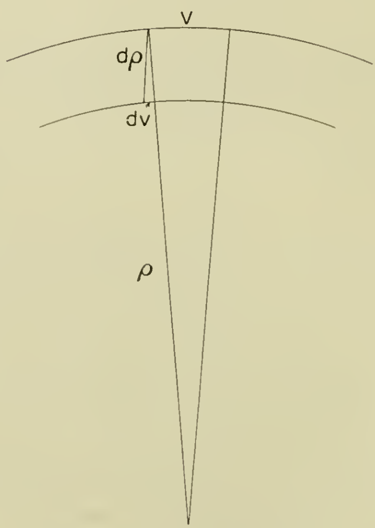
$$\frac{du}{ds} = \int \tan\alpha\;d\log\mu = \tan\alpha\;(\mu - 1) + a,$$

in which $a$ is the constant of integration and $\mu - 1$ is substituted for $\log_e\mu$, $\mu$ being but little greater than 1, and

$$u = \tan\alpha \int (\mu - 1)\,ds + as + b,$$

$$= \frac{\sin\alpha}{\cos^2\alpha}\int(\mu - 1)\,dz + as + b \;\ldots\ldots\;(C)$$

FIG. 128.




Curvature of a light path in the air.

But $\mu - 1$ is directly proportional to the density. Hence, if the height, $h$, in "the homogeneous atmosphere" be such that air below it is the same as below $z$ in the actual atmosphere, and if the origin be taken at the surface where $\alpha = \theta$, and $\mu = \mu_0$

$$u = \frac{\sin\theta}{\cos^2\theta}\int_0^h (\mu - 1)\,dz = \frac{\sin\theta}{\cos^2\theta}(\mu_0 - 1)\,h.$$

For the limit of the atmosphere, and any point beyond, $h = H$, the height of the homogeneous atmosphere, or about $7.990 \times 10$ cm.

For stars, therefore, viewed from the surface of the earth,

$$u = (\mu_s - 1)\, H \frac{\sin \theta}{\cos^2 \theta} \quad \ldots\ldots\ldots\ldots\ldots \quad (D)$$

Substituting this value of $u$ in $(B)$ we get

$$C = \frac{(\mu_s - 1)\, H}{\cos^2 \theta}.$$

Hence, substituting in $(A)$,

$$\mu_s R \sin \theta = \left\{ R + \frac{(\mu_s - 1) H}{\cos^2 \theta} \right\} \left\{ \theta + \delta \theta \right\}.$$

With this equation it is only a matter of arithmetic to compute a table of corrections, that is, values of $\delta\theta$ for every value of $\theta$ and $\mu_s$; $\theta$ being the apparent or observed zenith distance, and $\mu_s$ the current refraction at the surface, given by the equation

$$\mu_s = \frac{273 \mu_0 B}{760\, T}$$

in which $B$ is the height of the barometer in millimetres, $T$ the absolute temperature in degrees C., and $\mu_0$ atmospheric refraction at 0° C. and 760 mm. pressure.

Since $\delta\theta$ is small, we have from $(A)$, to a close approximation,

$$\begin{aligned}
\delta\theta = \sin \delta\theta &= \frac{\mu_s \tan\theta}{1 + C/R} - \tan \theta \cos \delta\theta \\
&= \tan\theta \left( \frac{\mu_s}{1 + C/R} - \sqrt{1 - \sin^2 \delta\theta} \right) \\
&= \tan\theta \left\{ \frac{\mu_s}{1 + C/R} - 1 + \tfrac{1}{2} (\delta\theta)^2 \right\} \\
&= \tan\theta \left\{ \mu_s - \frac{\mu_s C}{R} - 1 + \tfrac{1}{2} (\delta\theta)^2 \right\}, \text{ nearly.}
\end{aligned}$$

But, from the laws of refraction,

$$\mu_s \sin\theta = \sin (\theta + \delta\theta)$$

from which

$$\delta\theta = (\mu_s - 1) \text{ t n } \theta, \text{ nearly.}$$

Hence,

$$\delta\theta = (\mu_s - 1) \tan \theta \left\{ 1 - \frac{\mu_s C}{(\mu_s - 1) R} + \tfrac{1}{2} (\mu_s - 1) \tan^2 \theta \right\}, \text{ approximately.}$$

Substituting for $C$ its value and noting that

$$\frac{1}{\cos^2\theta} = 1 + \tan^2\theta,$$

this equation reduces to

$$\delta\theta = (\mu_s - 1)\left(1 - \frac{\mu_s H}{R}\right)\tan\theta - (\mu_s - 1)\left(\frac{\mu_s H}{R} - \frac{\mu_s - 1}{2}\right)\tan^3\theta$$

$$= (\mu_s - 1)\left(1 - \frac{H}{R}\right)\tan\theta - (\mu_s - 1)\left(\frac{H}{R} - \frac{\mu_s - 1}{2}\right)\tan^3\theta, \text{ nearly.}$$

If $H = 7.990 \times 10^5$ cm.; $R = 6.3709 \times 10^8$ cm.; and $\mu_s - 1 = .0002927$, all closely approximate values, then,

$$\delta\theta = 60''.29 \tan\theta - 0''.06688 \tan^3\theta.$$

This is Lord Rayleigh's final equation, and it appears to be exceedingly accurate for all values of $\theta$ up to at least 75°, or as far, perhaps, as irregular surface densities generally allow any refraction formula to be used with confidence.

Since the index of refraction varies from color to color, it follows that star images are drawn out into vertical spectra. The amount of this effect, however, is small. Thus the difference between the refractions of red and blue-green is only about one one-hundredth of the total refraction of yellow ($D$) light. Hence, the approximate angular distance between the red and blue-green images of a star at the zenith distances, 30°, 45°, 60° and 75° are 0″.35, 0″.60, 1″.04, and 2″.24, respectively. Possibly this may account, in part at least, for the fact that stellar declinations, as determined from the northern and southern hemispheres, respectively, are not quite the same.

*Scintillation or Twinkling and Unsteadiness of Stars.*—The scintillation or twinkling of stars, that is, their rapid changes in brightness and occasionally also in color, especially when near the eastern or western horizon, is a well-known, and now well-understood, phenomenon that for many centuries, certainly since the days of Aristotle (384–322 B.C.), who noted the fact that the fixed stars twinkle while the planets shine with comparatively steady lights, has been observed, investigated, and discussed. The most systematic and complete observations, however, of scintillation are those made by Respighi [168] with a spectroscope

[168] Assoc. Française pour l'Avancement des Sciences, I, 1872, p. 148.

during the years 1868–1869, and summed up substantially as follows:

(1) In the spectra of stars near the horizon more or less broad and distinct dark and bright bands sweep with greater or less velocity from the red to the violet and from the violet to the red or oscillate from the one to the other; and this whatever the direction of the spectra, from the horizontal to the vertical.

(2) When the conditions of the atmosphere are normal the dark and bright bands of western stars travel regularly from the red to the violet, and of eastern from the violet to the red; while in the neighborhood of the meridian they usually oscillate from the one color to the other, or even are limited to a portion of the spectrum.

(3) On examining the horizontal spectrum of a star sensibly parallel dark and bright bands more or less inclined to the axis (transverse) of the spectrum are seen passing from the red to the violet or reversely, according as the star is in the west or east.

(4) The inclination of the bands, or angle between them and the axis (transverse) of the spectrum, depends upon the altitude of the star; increasing rapidly from 0° at the horizon to 90° at an elevation of 30° to 40°, where they, therefore, are longitudinal.

(5) The inclination of the bands, reckoned from above, is towards the violet end of the spectrum.

(6) The bands, most distinct at the horizon, become less conspicuous with increase of elevation. Above 40° the longitudinal bands reduce to mere shaded streaks and often can be seen in the spectrum only as slight general changes of brightness.

(7) With increase of elevation the movement of the bands becomes more rapid and less regular.

(8) On turning the spectrum from the horizontal the inclination of the bands to the transversal continuously diminishes until it becomes zero, when the spectrum is nearly vertical. They also become less distinct, but continue always to move in the same direction.

(9) The bright bands are less frequent and more irregular than the dark, and are well-defined only in the spectra of stars near the horizon.

(10) In the midst of this general and violent movement of light and shade over the spectra of stars, the Fraunhofer lines peculiar to the light of each star remain quiescent or are subject to only very slight oscillations.

(11) When the atmospheric conditions are abnormal, the bands are fainter and more irregular in form and movement.

(12) When the wind is strong, the bands usually are quite faint and ill-defined; the spectra even of stars near the horizon showing mere changes of brightness.

(13) Good definition and regular movement of the bands appear to indicate the continuance of fair weather, while varying definition and irregular motion seem to imply a probable change.

These observations show that the dark bands are due to temporary deflection of light from the object glass by irregularities in the density of the atmosphere. For stars near the horizon, the linear separation of the rays of different color is so great as they pass through the atmosphere to the observer that successive portions of the spectrum may be deflected from or concentrated onto (light deficiencies in a transparent medium must be balanced by light concentrations, and *vice versa*), the telescope or eye. Hence, the progression of bright and dark bands along the spectra of low altitude stars, and their rapid change of color to the unaided eye.

Further, since the path of the more refrangible light necessarily lies above that of the less refrangible (Montigny's principle) it follows that an atmospheric irregularity travelling or

rotating with the earth would affect the different-colored rays from stars in the west in the order of red, green, blue, violet, and rays from stars in the east in the reverse order. If, then, the separation of the extreme rays is large in comparison to the effective dimension of the air irregularity, the resulting band will, at any given instant, cover only a portion of the spectrum. But the approximate amount of this separation is readily obtained from equation ($D$), page 445. Thus, for the limit of the atmosphere,

$$du = d\,\mu_s\,H\,\frac{\sin\theta}{\cos^2\theta}$$

Hence, at the zenith distance, 80°, the red and violet rays simultaneously received by the observer from the same star will be separated at the limit of the atmosphere (assuming the dispersion between these rays to be one-fiftieth the refraction of yellow light) by about 156 centimetres, and proportionately for levels below which definite fractions of the total mass of the atmosphere lie. For the zenith distance, 40°, however, the corresponding separation at the limit of the atmosphere is only about 5 centimetres, and for 20° about 2 centimetres. Inequalities in the atmosphere may, therefore, interfere with only a portion at a time of the spectrum of a star near the horizon and thus produce the phenomenon of a travelling band, while in the case of a star whose zenith distance is 40°, or less, the interference will include nearly or quite the entire spectrum, and thus produce mere changes of brightness.

It is generally stated that the direction of travel of the bands during fine weather, red to violet for stars in the west, violet to red for stars in the east, and irregularly or simultaneously over the entire spectrum for stars near the meridian, is directly dependent upon the west to east rotation of the earth. It is correctly stated (on assumption of a stationary atmosphere) that this rotation would cause an atmospheric irregularity to affect the red rays first and the violet last, violet first and red last, and all rays more or less simultaneously, of stars in the west, east, and near the meridian, respectively. But the order would be the same if the earth were at rest and the air travelling from west to east. As a matter of fact, over most of the earth outside the tropics the west to east angular velocity of the general winds, as seen by the observer, is several times that of the earth. Hence,

the rate at which the disturbance drifts across the line of sight presumably depends much more on the direction of the prevailing winds than upon the rotation of the earth. Indeed, in tropical regions, where the prevailing winds are from easterly points, the usual direction of travel of the bands probably (if the above reasoning is correct) is reversed.

The disappearance of distinct bands with high winds is due, of course, to the more complete mixing of the atmosphere at such times.

In the same general way, atmospheric inequalities produce "unsteadiness," or rapid changes in the apparent positions of stars as seen in a telescope. In reality, this is a telescopic form of scintillation which, because never amounting to more than a very few seconds of arc, the unaided eye cannot detect. On the other hand, the great changes in brightness and color so conspicuous to the naked eye are scarcely if at all noticeable in a large telescope. This is because the object glass is so large that, in general, light deflected from one portion of it is caught in another.

*Scintillation of the Planets, Sun, and Moon.*—It is commonly stated that the planets do not scintillate—that the light from the several portions of their disks follow such different paths through the atmosphere that not all nor even any large portion of it can be affected at any one time. It is true that because of their sensible disks the scintillation of planets is much less than that of fixed stars, but under favorable circumstances their scintillation is quite perceptible. Even the rims of the sun and the moon boil or "scintillate" while, of course, any fine marking on either or on a planet is quite as unsteady as the image of a fixed star.

*Nature of Irregularities.*—It is well known that the atmosphere, generally, is so stratified that with increase of elevation many more or less abrupt changes occur in temperature, composition, density, and, therefore, refrangibility. As such layers glide over each other, billows are formed, and the adjacent layers thereby corrugated. The several layers frequently also heat unequally, largely because of disproportionate vapor contents, and thereby develop, both day and night, and at various levels, innumerable vertical convections; each moving mass differing, of course, in density from the surrounding air, and by the chang-

ing velocity being drawn out into dissolving filaments. Optically, therefore, the atmosphere is so heterogeneous that a sufficiently bright star shining through it would produce on the earth a somewhat streaky pattern of light and shade.

*Shadow Bands.*—A striking proof of the optical streakiness of the atmosphere is seen in the well-known shadow bands that at the time of a total solar eclipse appear immediately before the second, and after the third, contact.

*Terrestrial Scintillation.*—A bright terrestrial light of small size, such as an open electric arc, scintillates when seen at a great distance, quite as distinctly as do the stars and for substantially the same reason, that is, optical inequalities due to constant and innumerable vertical convections and conflicting winds.

*Shimmering.*—The tremulous appearance of objects, the common phenomenon of shimmering, seen through the atmosphere immediately over any heated surface, is another manifestation of atmospheric refraction, and is due to the innumerable fibrous convections that always occur over such an area.

*Optical Haze.*—The frequent indistinctness of distant objects on warm days when the atmosphere is comparatively free from dust, and ascribed to optical haze, is due to the same thing, namely, optical heterogeneity of the atmosphere, that causes that unsteadiness or dancing of star images that so often interferes with the positional and other exact work of the astronomer. Both are but provoking manifestations of atmospheric refraction.

*Times of Rising and Setting of Sun, Moon, and Stars.*—An interesting and important result of astronomical refraction is the fact that the sun, moon, and stars rise earlier and set later than they otherwise would. For places at sea level the amount of elevation of celestial objects on the horizon averages about 35′, and therefore the entire solar and lunar disks may be seen before (on rising) and after (on setting) even their upper levels would have appeared, in the first case, or disappeared, in the second, if there had been no refraction. This difference in time of rising, or setting, depends on the angle or inclination, $\alpha$, of the path to the horizon. In general, it is given by the equation,

$$t = 140^s \csc\alpha, \text{ about.}$$

The minimum time, therefore, occurs when the path is normal to the horizon and is about $2^m\ 20^s$, while the maximum, which

obviously occurs at the poles, is infinite in the case of stars that just clear the horizon, and, for the sun, about a day and a half, the time required near equinox for the solar declination to change by 35′.

*Green Flash.*—As the upper limb of the sun disappears in a clear sky below a distant horizon its last star-like point often is seen to change rapidly from pale yellow or orange to green and finally blue, or, at least, a bluish-green. The vividness of the green, when the sky is exceptionally clear, together with its almost instant appearance, has given rise to the name " green flash " for this phenomenon The same gamut of colors, only in reverse order, occasionally is seen at sunrise.

The entire phenomenon has been described by some as merely a complementary after-image effect, that is, the sensation of its complementary color that frequently follows the sudden removal of a bright light. This explanation, however, cannot account for the reverse order of the colors as seen at sunrise. Neither does it account for the twinkling of the " flash " close observation now and then reveals, nor for the fact that when the sun is especially red the " flash " is never seen.

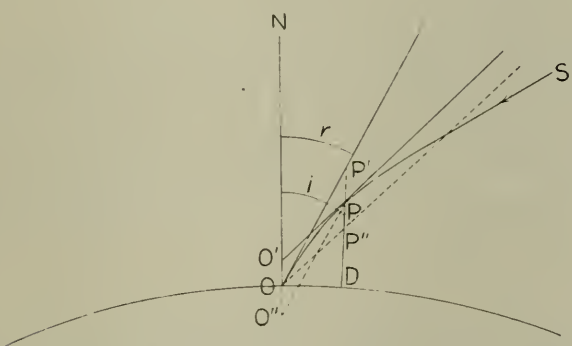
It is not, indeed, a physiological effect, but only the inevitable result of atmospheric refraction, by virtue of which as a celestial object sinks below the horizon its light must disappear in the order of refrangibility; the red first, being least refrangible, then the green, and finally the blue or most refrangible. Violet need not be considered, since only a comparatively small portion of it can penetrate so far through the atmosphere.

It may properly be asked, then, why these color changes do not apply to the whole solar disk. The answer is, because the angular dispersion, due to the refraction of the atmosphere, between the several colors is very small—between red and green, for instance, only about 20″, even when the object is on the horizon, so that any color from a given point on the sun is reinforced by its complementary color, thus giving white from a closely neighboring point. Hence, color phenomena can appear only when there are no such neighboring points, or when only a minute portion of the disk is above the horizon. It must further be noted that color effects, due to the general refraction of the atmosphere, occur only when the source (brilliant point) is on the horizon. Stars above the horizon are not permanently drawn out

into rainbow bands, and that for the simple reason that the red light by one route is supplemented by the green, blue, etc., by others and the whole blended into white, yellow, or whatever the real color of the star may be. This multiplicity of routes and consequent blending of color, is not possible for rays of light from objects just sinking below or rising above the horizon, and, therefore, under such circumstances, they pass through a series of color changes.

*Terrestrial Refraction.*—The curving of rays of light is not confined to those that come from some celestial object, but applies also to those that pass between any points within the atmosphere, whether at the same or different levels. This latter

FIG. 129.




Approximate terrestrial refraction.

phenomenon, known as terrestrial refraction, causes all objects on the earth or in the atmosphere to appear to be at greater altitudes than they actually are, except when the surface air is so strongly heated as to cause an *increase* of density with elevation and thus produce the inferior mirage, described below.

Terrestrial refraction is also a matter of great importance, especially to the geodesist, and its complete analysis, from which practical tables may be constructed, essentially the same as that of astronomical refraction. It will be instructive, however, to consider a few graphical corrections of apparent elevations.

Let $ON$ (Fig. 129) be normal to the surface, $OD$, of the earth, and let $P$ be observed from $O$. Obviously $P$, whose horizontal distance, $OD$, may be supposed known, will seem to be at $P'$ and thus its apparent altitude greater than the actual by the distance

$PP'$. From the angle $r$, the density of the air at the observer's position, $O$, and the approximate density at $P$ (known from the approximate height of $P$) it is easy to draw $OP''$ parallel to the tangent at $P$ to the refraction curve, $SPO$. This gives $P''$, necessarily below $P$. Hence $P$ lies somewhere between $P'$ and $P''$.

A more exact determination could be had by drawing the curve of refraction, $OPS$, corresponding to the angle $r$ and noting its intersection with the normal at $D$.

If the observer happens to be at $P$, the point $O$ will appear elevated to $O'$. Clearly, however, from a knowledge of the angle $PO'N$, and the approximate air densities at $P$ and $O$, one may draw $PO''$ parallel to $P'O$, and thus locate $O$ somewhere between the two determined points $O'$ and $O''$. Here, too, it would be more accurate to use the refraction curve, $SPO$.

Even initially horizontal rays normally curve down towards the surface of the earth, so that objects at the observer's own level, as well as those above and below it, appear elevated. To understand this phenomenon, consider a wave front normal to the surface of the earth and, consequently, moving horizontally. If, now, the density of the air at the place in question decreases with increase of elevation, as it nearly always does, the upper portion of the wave front will travel faster than the lower, and the path will be bent down towards the earth along a curve whose radius depends upon the rate of this density decrease. For example, let the corrected height of the barometer be 760 mm., the temperature 17° C., and the rate of temperature decrease with elevation 5° C. per kilometer; conditions that not infrequently obtain at sea level. On substituting these values in the density-elevation equation, it appears that the density gradient would be such that if continuous the limit of the atmosphere would be reached at an elevation of about 10 kilometres. Hence, under these circumstances, the velocity of light at an elevation of 10 kilometres would be to its velocity at the surface in the ratio of 1,000,276 to 1,000,000, approximately, since the refractive index of the lower air would be 1,000,276, about. The radius of curvature, $r$, therefore, is closely given in kilometres by the equation,

$$\frac{r}{r+10} = \frac{1{,}000{,}000}{1{,}000{,}276}.$$

Hence, $r = 36{,}232$ kilometres, or approximately 5.7 times the radius of the earth.

It is conceivable, therefore, that the size of a planet and the vertical density gradient of its atmosphere might be such that one's horizon on it would include the entire surface—that he could look all the way round and, as some one has said, see his own back.

The distance to the horizon, corresponding to a given altitude, obviously depends upon the rate of vertical density decrease in such manner that when the latter is known the approximate value of the former can easily be computed. Thus, let the density decrease be such that the radius of curvature of a ray tangent to the surface shall be 5.7 $R$, $R = 6366$ kilometres, being the radius of the earth; let $\alpha$ be the angle betwen the radii from the centre of the earth to the observer and a point on his unobstructed horizon respectively; let $h$ be the observer's height in metres above the level of his horizon; and let $r$ be the distance, in kilometres, measured over the surface from the horizon to a point on the same level below the observer; then, by trigonometry, to a close approximation;

$$h = 6366000 (\sec\alpha - 1) - 36286200 \left(\sec \frac{\alpha}{5.7} - 1\right) \sec\alpha$$

and

$$r = 6366\alpha, \ \alpha \text{ in radians}$$

A few values of the distance to the horizon from different elevations, computed by the above formula, are given in the following table:

*Distance to Horizon.*

| Distance in Kilometres. | 1 | 2 | 5 | 10 | 20 | 50 | 100 |
|---|---|---|---|---|---|---|---|
| Elevation in metres. | .061 | .263 | 1.613 | 6.856 | 25.901 | 161.918 | 647.604 |

*Looming.*—Since the extension of the actual beyond the geometrical horizon depends, as just explained, upon the density decrease of the atmosphere with increase of elevation, it follows that any change in the latter must produce a corresponding variation of the former. An increase, for instance, in the normal rate of decrease, such as often happens over water in middle to high latitudes, produces the phenomenon of looming, or the coming into sight of objects normally below the horizon, a classical in-

stance of which was described by Latham.[169] Similar changes in the rate of density decrease with increase of elevation also are common in valleys, but here looming, in the above sense, is rendered impossible by the surrounding hills or mountains.

*Towering.*—The condition of the atmosphere that produces looming, in the sense here used, or would produce it if the region were level, often gives rise to two other phenomena, namely, unwonted towering, also usually called looming, and the consequent apparent approach of surrounding objects.

The more rapid the downward curvature of the ray paths at the observer the more elevated, clearly, will objects appear to be, and such curvature may, indeed, be very considerable. Thus, a temperature inversion near the surface of the earth of 1° C. per metre change of elevation bends down a ray along an arc whose radius is about 0.16 that of the earth, while an inversion of 10° C. per metre—a possible condition through a shallow stratum—gives a radius of only about 0.016 that of the earth, or, say, 100 kilometres. If now, as occasionally happens, the inversion layer is so located that rays to the observer from the top of an object are more curved than those from the bottom, it will appear not only elevated but also vertically magnified—it will tower and seem to draw nearer.

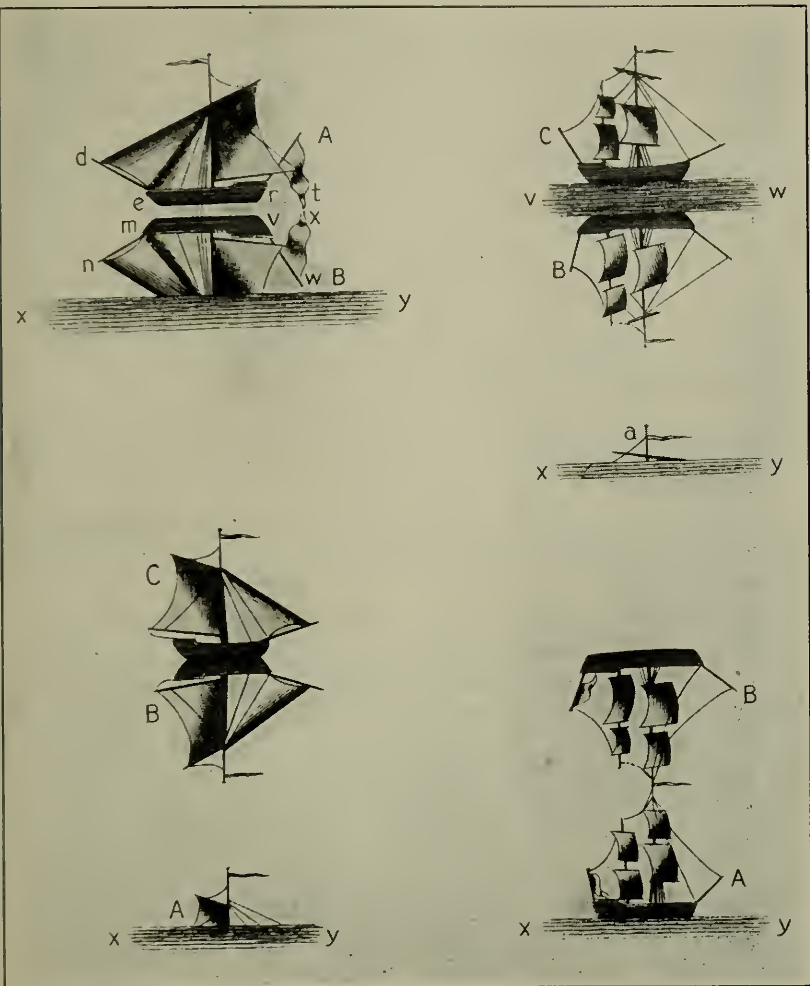
*Sinking.*—Instead of increasing the curvature of rays the temperature distribution may be such as, on the contrary, to decrease it and thereby cause objects normally on the horizon to sink quite beyond it. Such phenomena, exactly the reverse of looming, are also most frequently observed at sea.

*Stooping.*—Occasionally rays from the base of an object may be curved down much more rapidly than those from the top, with the obvious result of apparent vertical contraction, and the production of effects quite as odd and grotesque as those due to towering. Indeed, since the refraction of the atmosphere increases, in general, with the zenith distance, it is obvious that the bases of objects nearly always apparently are elevated more than their tops, and themselves, therefore vertically shortened. The normal effect, however, is small and seldom noticed except, perhaps, in connection with the slightly flattened shape of the sun and moon when on the horizon.

[169] *Phil. Trans.*, v. **88**, 1798; abridged, v. **18**, p. 337. See also Everett, "Nature," v. **11**, p. 49, 1874.

*Superior Mirage.*—It occasionally happens that one or more images of a distant object, a ship for instance, are seen directly

FIG. 130.




Examples of superior mirage (Vince).

above it, as shown in Fig. 130, copied from Vince's [170] well-known description of exceptionally fine displays of this phenomenon.

[170] *Phil. Trans.*, **89** (8, abridged, p. 436), 1799.

The mirage nearest the object always is inverted and therefore appears as though reflected from an overhead plane mirror—hence the name "superior mirage"—and, indeed, many seem to assume that this image really is due to a certain kind of reflection, that is, total reflection, such as occurs at the undersurface of water. It is obvious, however, that this assumption is entirely erroneous, since the atmosphere can never be sufficiently stratified in nature to produce the discontinuity in density (adjacent layers are always interdiffusible) this explanation of the origin of the proximate inverted image presupposes. Another apparently simple explanation of mirage phenomena is furnished by drawing imaginary rays from the object along arbitrary paths to the observer. But, in reality, this is no explanation at all, unless it is first demonstrated that the rays must follow the paths assumed. It is allowable, of course, to assume any *possible* distribution of atmospheric density and to trace the rays from an object accordingly. If the assumed distribution follows a simple law, the rays may be traced mathematically, as by Mascart,[171] though such discussions, when at all thorough, necessarily are long.

A simple explanation of mirage that admirably accounts for the phenomena observed has been given by Hastings,[172] in substance as follows:

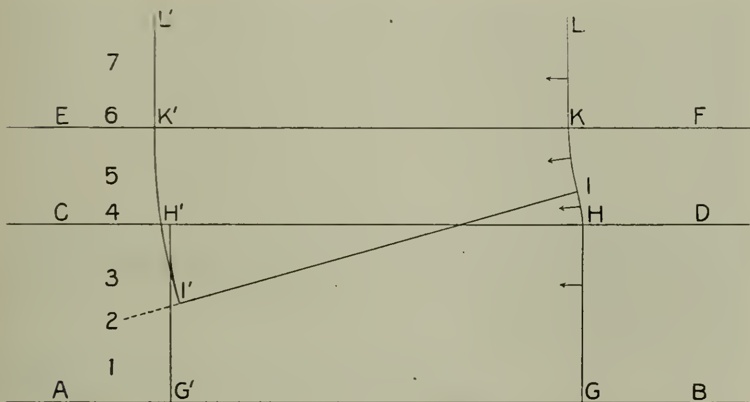
Let the air be calm and let there be a strong temperature inversion some distance, 10 metres, say, above the surface—conditions that occasionally obtain, especially over quiet water. Obviously the ratio of decrease of density to increase of elevation is irregular in such an atmosphere, and therefore the velocity of light travelling horizontally through it must increase also irregularly with increase of elevation. Thus, beginning with the undersurface of the inversion layer, the rate of velocity increase with elevation must first grow to a maximum and then diminish to something like its normal small value at and beyond the upper surface of this layer. Hence, that portion of an originally vertical, or approximately vertical, wave front that lies within the inversion layer must soon become doubly deflected, substantially as indicated in Fig. 131.

[171] "Traité d'Optique," v. 3, pp. 305–308.

[172] "Light," Chapter 7, New York, Chas. Scribner's Sons, 1902.

Let $AB$ (Fig. 131) be the surface of water, say, $CD$ the under and $EF$ the upper surface of a strong inversion layer, and let $GHIKL$ be the distorted wave front of light, travelling in the direction indicated, from a distant source. The future approximate positions of the wave front, of which $G'H'I'K'L'$ is one, are readily located from the fact that its progress is always normal to itself, and the appearance of the distant object from which these wave fronts are proceeding easily determined. At 1, for instance, the object seems upright and at its proper level, no images are seen and the whole appearance is normal; at 2 confused elevated images appear, in addition to the object itself; at 3 the

FIG. 131.




Wave fronts giving a superior mirage (Hastings).

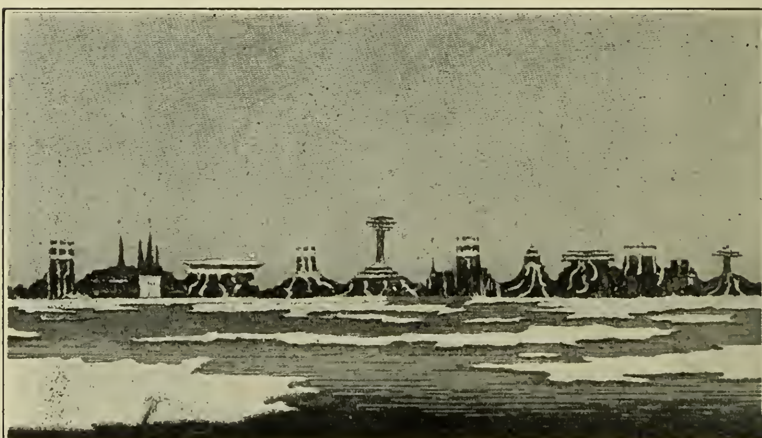
object and 2 distinct images are seen, the lower produced by the segment $HI$ of the wave front inverted, the other erect; at 4, the under surface of the inversion layer, the inverted image blends with the object and disappears; at 5 only the erect image can be seen, and, indeed, may be seen even when the object itself normally would be below the horizon; at 6, the upper surface of the inversion layer, the vertical image merges with the object and disappears; while everywhere beyond the upper surface only the object itself is visible, as at 1, with no evidence whatever of abnormal refraction and mirage.

An additional inversion layer obviously might produce other images, while more or less confused layers might produce multiple and distorted images, such as shown in Fig. 132, copied from

Scoresby's account [173] of a certain telescopic view of the east coast of Greenland.

*Inferior Mirage.*—It is a very common thing in flat desert regions, especially during the warmer hours of the day, to see below distant objects and somewhat separated from them their apparently mirrored images—the inferior image. The phenomenon closely simulates, even to the quivering of the images, the reflection by a quiet body of water of objects on the distant shore, the "water" being the image of the distant low sky, and therefore frequently leads to the false assumption that a lake or bay

FIG. 132.



Telescopic appearance of the coast of Greenland, at the distance of 35 miles, when under the influence of an extraordinary refraction. July 18, 1820. Lat. 71° 20′, Long. 17° 30′ W.

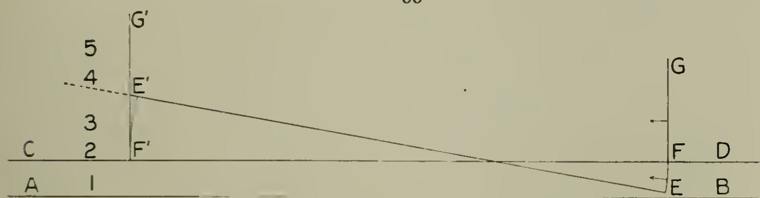
is close by. This type of mirage is very common on the west coast of Great Salt Lake. Indeed, on approaching this lake from the west one can often see the railway over which he has just passed apparently disappearing beneath a shimmering surface. It is also common over smooth-paved streets provided one's eyes are just above the street level. An under-grade crossing in a level town, for instance, offers an excellent opportunity almost any warm day of seeing well-defined small images that are apt to arouse one's surprise at the careless way his fellow-citizens wade through pools of water!

[173] *Trans. Roy. Soc. Edinburgh*, v. 9, p. 299, 1823.

Since the inferior mirage occurs only over approximately level places and there only when they are so strongly heated that for a short distance the density of the atmosphere increases with elevation it follows that its explanation is essentially the same as that of the superior mirage. Of course, the surface air is in unstable equilibrium and rising in innumerable filaments, but its rarefied state is maintained so long as there is an abundant supply of insolation. A wave front, therefore, from an object slightly above the general level soon becomes distorted through the greater speed of its lower portion, as schematically indicated in Fig. 133.

Let *AB* of this figure be the surface of the earth and *CD* the upper level of the superheated stratum. Let *EFG* be the position of a wave front travelling as indicated, the lower portion curved forward as a result of its greater speed in the rarefied

FIG. 133.




Wave fronts giving an inferior mirage (Hastings).

layer. One of the consequent later positions of the wave front is shown at *E'F'G'*, from which it follows that at 1 neither the object in question nor any image of it can be seen; at 2 the object and its inverted image are glimpsed, superimposed; at 3 both the object and its inverted image, well below it, are plainly visible; at 4 the image is just disappearing; while at 5 there is no evidence of a mirage, unless of objects more distant than the one under consideration.

Great uncertainty may exist, therefore, in regard to the exact positions of objects seen in (or perhaps hidden by) a mirage. Thus, in his official report of the battle of April 11, 1917, between the English and the Turks in Mesopotamia, General Maude, the British commander, says: " The fighting had to be temporarily suspended owing to a mirage."

*Lateral Mirage.*—Vertical sheets of abnormally dense or abnormally rare atmosphere obviously would produce lateral mirages in every way like those due to similar horizontal layers,

and indeed such mirages are occasionally seen along walls and cliffs whose temperatures differ widely from that of the air a few metres from them.

*Fata Morgana.*—Morgana (Breton equivalent of sea woman), according to Celtic legend and Arthurian romance, was a fairy, half-sister of King Arthur, who exhibited her powers by the mirage. Italian poets represent her as dwelling in a crystal palace beneath the waves. Hence, presumably, the name Fata Morgana (Italian for Morgan le Fay, or Morgan the fairy) was given, centuries ago, to those complicated mirages that occasionally appear over the strait of Messina moulding the bluffs and houses of the opposite shore into wondrous castles that alike tower into the sky and sink beneath the surface; nor is it strange that this poetical name should have become generic, as it has, for all such multiple mirages wherever they occur.

According to Forel,[174] this phenomenon, to which he has given much attention, results from the coexistence of the temperature disturbances peculiar to both the inferior and superior mirages, such as might be produced by a strong inversion over a relatively warm sea. This, of course, implies a marked increase of density with elevation to a maximum a short distance above the surface, followed by a rapid density decrease—an unstable condition and therefore liable to quick and multiform changes. Obviously, too, such a cold intermediate layer in addition to producing a double mirage acts also as a sort of cylindrical lens that vertically magnifies distant objects seen through it.

No wonder, then, that under such circumstances the most commonplace cliffs and cottages are converted, through their multiple, distorted, and magnified images, into magic castles, or the marvellous crystal palaces of Morgan le Fay!

## Chapter III.

### REFRACTION PHENOMENA: REFRACTION BY WATER DROPS—RAINBOW.

*Principal Bows.*—It may seem entirely superfluous to describe so common a phenomenon as the rainbow, or to offer more than the simple explanation of it that may be found in innumerable text-books. But rainbows differ among themselves as one tree

[174] *Archives des Sciences Phys. et Nat.*, v. 32, p. 471, 1911.

from another, and besides some of their most interesting features usually are not even mentioned—and naturally so, for the "explanations" generally given of the rainbow may well be said to explain beautifully that which does not occur and to leave unexplained that which does.

The ordinary rainbow, seen on a sheet of water drops—rain or spray—is a group of circular or nearly circular arcs of colors whose common centre is on the line connecting the observer's eye with the exciting light (sun, moon, electric arc, etc.) or rather, except rarely, on that line extended in the direction of the observer's shadow. A very great number of rainbows are theoretically possible, as will be explained later, and doubtless all that are possible actually occur, though only three (not counting supernumeraries) certainly have been seen on sheets of rain. The most brilliant bow, known as the *primary,* with red outer border of about 42° radius and blue to violet inner border, appears opposite the sun (or other adequate light); the next brightest, or the *secondary* bow, is on the same side of the observer, but the order of its colors is reversed and its radius, about 50° to the red, is larger; the third or *tertiary* bow, having about the same radius as that of the primary and colors in the same order, lies between the observer and the sun, but is so faint that it is rarely seen in nature. Obviously the common centre of the primary and secondary bows is angularly as far below the observer as the source (sun generally) is above, so that usually less than a semicircle of these spectral arcs is visible, and never more, except from an eminence.

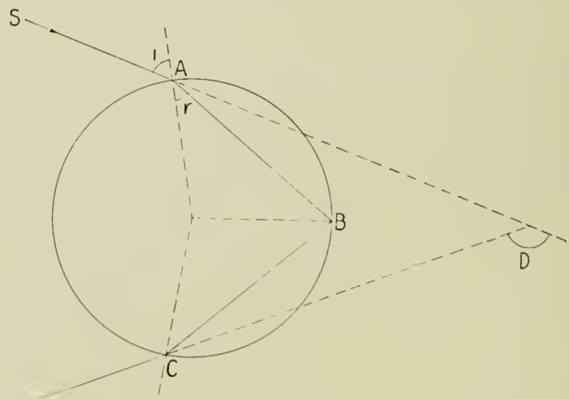
The records of close observations of rainbows soon show that not even the colors are always the same; neither is the band of any color of constant angular width; nor the total breadth of the several colors at all uniform; similarly the purity and brightness of the different colors are subject to large variations. The greatest contrast, perhaps, is between the sharply-defined brilliant rainbow of the retreating thunderstorm and that illy-defined faintly tinged bow that sometimes appears in a mist—the "white bow" or "fog bow."

All these differences depend, as will be explained later, essentially upon the size of the drops, and therefore inequalities often exist between even the several portions, especially top and bottoms, of the same bow, or develop as the rain progresses. Ad-

ditional complications occasionally result from the reflection of bows and from bows produced by reflected images of the sun, but though unusual and thus likely to excite wonder and comment such phenomena are easily explained.

*Supernumerary Bows.*—Rather narrow bands of color, essentially red, or red and green, often appear parallel to both the primary and the secondary bows, along the inner side of the first and outer of the second. These also differ greatly in purity and color, number visible, width, etc., not only between individual bows but also between the several parts of the same bow. No such colored arcs, however, occur between the principal bows; indeed, on the contrary, the general illumination here is perceptibly at a minimum.

Fig. 134.




Change in light direction by raindrop.

*Deviation in Direction of Emerging from Entering Ray.*—Since a raindrop is spherical, its action on an enveloping wave front may be obtained by determining first the effects in the plane of a great circle containing an entering ray, and then revolving this plane about that line in it that bisects the angle between the incident and emerged paths of any given ray in the same plane. Let, then, $ABC$ (Fig. 134) be the plane of a great circle of an enlarged raindrop and let $S\ A\ B\ C\ E$ be the path of a ray in this plane, entering the drop at $A$ and emerging at $C$. The changes in direction at $A$ and $C$ are each $i-r$, in which $i$ is the angle of incidence and $r$ the angle of refraction, and the change at $B$, as

also at every other place of an internal reflection, when there are more than one, is $\pi - 2r$. Hence, the total deviation, $D$, is given by the equation,

$$D = 2(i - r) + n(\pi - 2r) \quad \ldots\ldots\ldots\ldots \quad (1)$$

in which $n$ is the number of internal reflections.

*Minimum Deviation.*—The above general expression for the deviation shows that it varies with the angle of incidence. There is also a minimum deviation, corresponding to a particular angle of incidence, as may be shown in the usual way. Thus by equation (1),

$$dD = 2di - 2(n + 1)\,dr$$

which, on putting $dD = O$, the condition of stationary (maximum or minimum) deviation, gives,

$$di = (n + 1)\,dr \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

But $\sin i = \mu \sin r$, in which $\mu$ is the refractive index of water with reference to air, and, therefore,

$$\cos i\ di = \mu \cos r\ dr.$$

Hence, by (2)

$$\mu \cos r = (n + 1) \cos i$$

and

$$\cos i = \sqrt{\frac{\mu^2 - 1}{n^2 + 2n}}.$$

This value of the angle of incidence corresponds, as stated, to a stationary deviation, but whether of maximum or minimum value may be determined by noting the sign of the second differential, which gives:

$$\frac{d^2D}{di^2} = -2(n + 1)\frac{d^2r}{di^2}$$

But

$$\frac{dr}{di} = \frac{\cos i}{\mu \cos r},$$

and

$$\frac{d^2r}{di^2} = \frac{(1 - \mu^2) \sin i}{\mu^3 \cos^3 r},$$

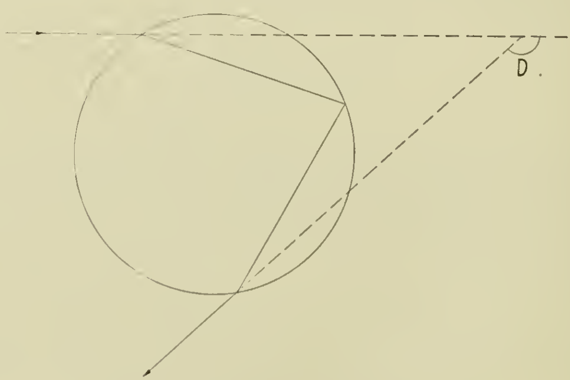
Hence, as $\mu$ is greater than unity, this latter value is negative and therefore the second differential of $D$ with respect to $i$ is positive, and the corresponding value of $D$ is a minimum.

The following table gives these values for the primary, secondary, tertiary, quaternary, and quinary rainbows corresponding to 1, 2, 3, 4, and 5 internal reflections, respectively, as shown in Figs. 135, 136, 137, 138, and 139.

| | | $n=1$ | $n=2$ | $n=3$ | $n=4$ | $n=5$ |
|---|---|---|---|---|---|---|
| Violet, H | $i$ | 58° 48′ | 71° 30′ | 76° 36′ | 79° 27′ | 81° 17′ |
| $\lambda=3968.5$ | $r$ | 39° 33′ | 44° 54′ | 46° 23′ | 47° 2′ | 47° 22′ |
| $\mu=1.3435$ | $D$ | $\pi-40°\ 36'$ | $2\pi-126°\ 24'$ | $2\pi-37°\ 52'$ | $3\pi-131°\ 26'$ | $3\pi-45°\ 50'$ |
| Yellow | $i$ | 59° 23′ | 71° 50′ | 76° 50′ | 79° 38′ | 81° 26′ |
| $\lambda=$ 5800.0, about | $r$ | 40° 12′ | 45° 27′ | 46° 55′ | 47° 32′ | 47° 52′ |
| $\mu=4/3$ | $D$ | $\pi-42°\ 2'$ | $2\pi-129°\ 2'$ | $2\pi-41°\ 40'$ | $3\pi-136°\ 4'$ | $3\pi-51°\ 32'$ |
| Red, *Hα* | $i$ | 59° 31′ | 71° 54′ | 76° 53′ | 79° 40′ | 81° 28′ |
| $\lambda=6562.9$ | $r$ | 40° 21′ | 45° 34′ | 47° 2′ | 47° 39′ | 47° 59′ |
| $\mu=1.3311$ | $D$ | $\pi-42°\ 22'$ | $2\pi-129°\ 36'$ | $2\pi-42°\ 30'$ | $3\pi-137°\ 10'$ | $3\pi-52°\ 52'$ |

*Entering and Emerging Rays.*—Since a raindrop is spherical, it is obvious that its effect on incident radiation from the sun, or other spherical or point source, is symmetrical about an axis

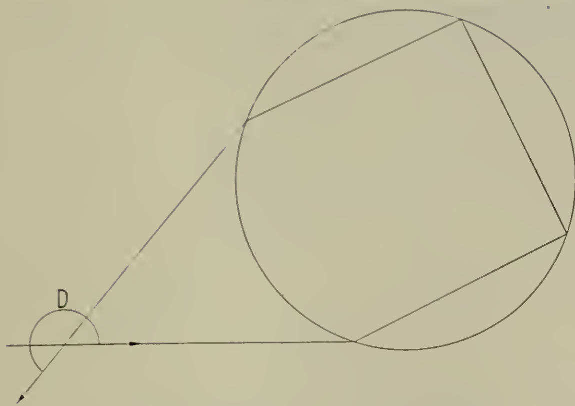
FIG. 135.




Change of light direction in primary rainbow.

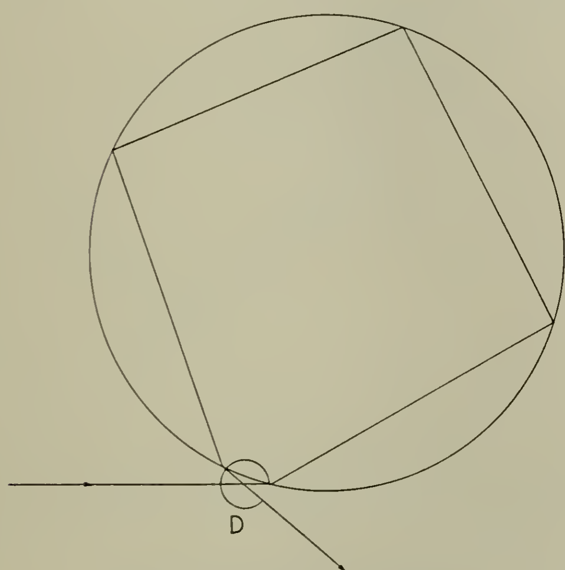
through the centre of the drop and the luminous object. Hence, in the study of the rainbow, it is sufficient to use only a single plane containing this axis, tracing the rays incident over one quadrant of the intersection circle and noting the resulting phenomena. It is also obvious that, neglecting sky light, solar rays

FIG. 136.




Change of light direction in secondary rainbow.

FIG. 137.

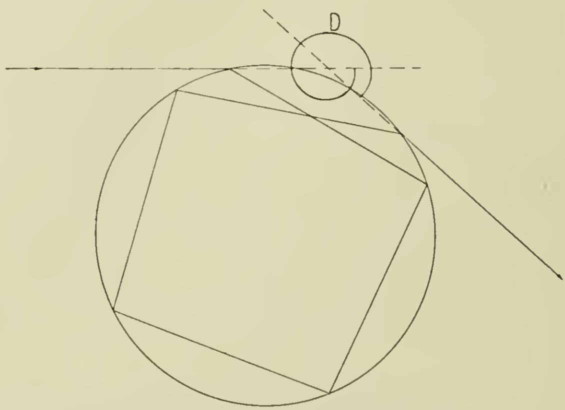



Change of light direction in tertiary rainbow.

are parallel to within the angular diameter of the sun, 0.5° about, and that as a first approximation they may be regarded as strictly parallel. Let, then, the plane of Fig. 140 pass through the centres of a raindrop and the sun, and let *AB* be the wave front

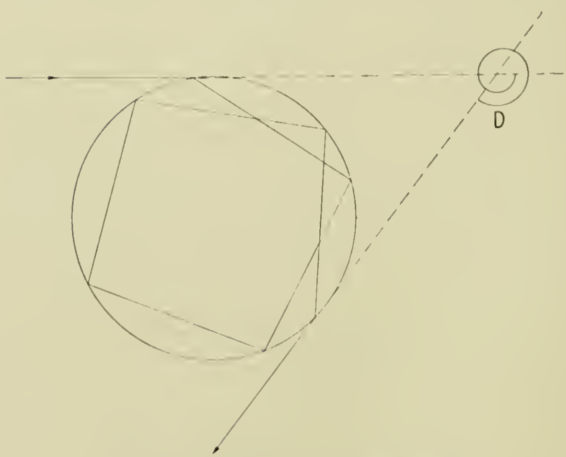
of parallel rays incident, as shown, above the normal or axial ray (ray passing through centre of drop). An equal amount of light clearly enters below the normal ray, but for simplicity this is

FIG. 138.




Change of light direction in quaternary rainbow.

FIG. 139.

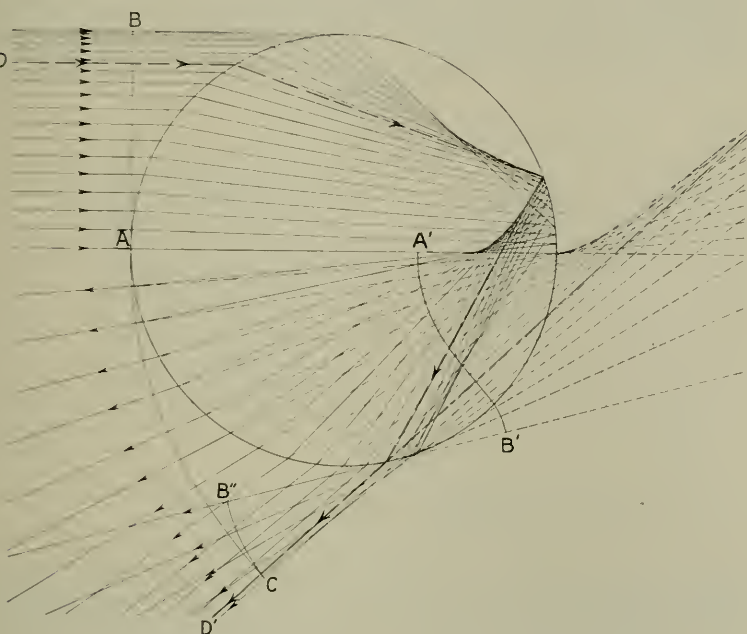



Change of light direction in quinary rainbow.

omitted. Similarly that portion reflected from the outer surface is ignored, as is also all that is internally reflected more than once. This reduces the problem of the rainbow to its simplest terms, but loses none of its generality, since additional internal

reflections merely change angular dimensions and brightness. The heavy line shows the course of the Descartes ray, or ray of minimum deviation for light of air-water refractive index, 4/3. The courses of other rays are, very approximately, as indicated. Since the deviations of the rays incident between the axial and the Descartes rays are greater than that of the Descartes, it follows that their exits are, as shown, between those of the same two

FIG. 140.




Course of light through a raindrop and the corresponding wave fronts.

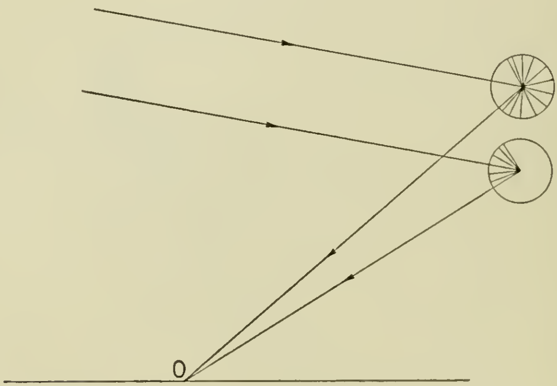
rays. Similarly, all rays that enter beyond the Descartes ray are likewise more deviated, and, therefore, while they leave the drop beyond this ray, they do so in such direction as sooner or later also to come between it and the axial ray, substantially as shown. Clearly, then, the once reflected light is diffuse and feeble except near the path of minimum deviation, and confined, as indicated, to the region between this path and the axial ray.

*Formation of the Bow.*—From the course, just given, of light through raindrops, it is clear that maximum brightness will be produced by all illuminated drops along the elements of a right

circular cone whose vertex is at the eye, whose axis passes through the sun, and whose angular opening, corresponding to a given number of internal reflections, is determined by the wave-length. Hence, the rainbow exhibits a number of concentric circular arcs of different colors whose centres are angularly as far below the observer as the sun is above him.

*Minimum Brightness Between Primary and Secondary Bows.*—Careful observers often note the fact that the region between the primary and secondary bows is slightly darker than any other in the same general direction. The explanation of this phenomenon is very simple. As the deviation of no ray can be less than

FIG. 141.



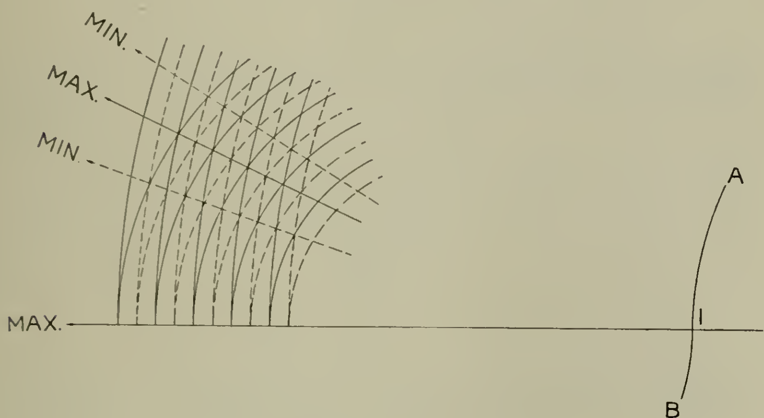

Minimum light between primary and secondary rainbows.

that of the Descartes, it is clear that all light pertaining to any given number of internal reflections must leave a drop within a cone formed by the rotation of a corresponding Descartes ray about the axial ray, keeping the angle between them constant as shown in Fig. 141 for light of 1, and 2 internal reflections, respectively. Hence, once reflected light reaches an observer from drops along and within his primary bow, but none from those without, while twice reflected light reaches him from along and without the secondary bow, but none from within it. The region between the two bows, therefore, and it alone, is devoid of both the once and the twice reflected rays and in consequence is comparatively dark.

*Origin of Supernumerary Bows.*—Since wave fronts are normal to the corresponding rays, it is clear that the incident

front, $AB$ (Fig. 140), will, at the moment of complete emergence, appear as $ACB''$—exactly as though it had come from the virtual front, $A'B'$, the locus of the terminus of a line of constant length, $AA'$, as it travels normally over the emerging wave front, $ACB''$. Further, since the rays here lie on both sides of the one of minimum deviation, it is obvious that this ray divides $A'B'$ into two portions curved in opposite directions. That portion of the front that is convex forward will, of course, remain convex, but with increasing radii of curvature, while the part that is concave forward will later become convex, and although neither portion is

FIG. 142.



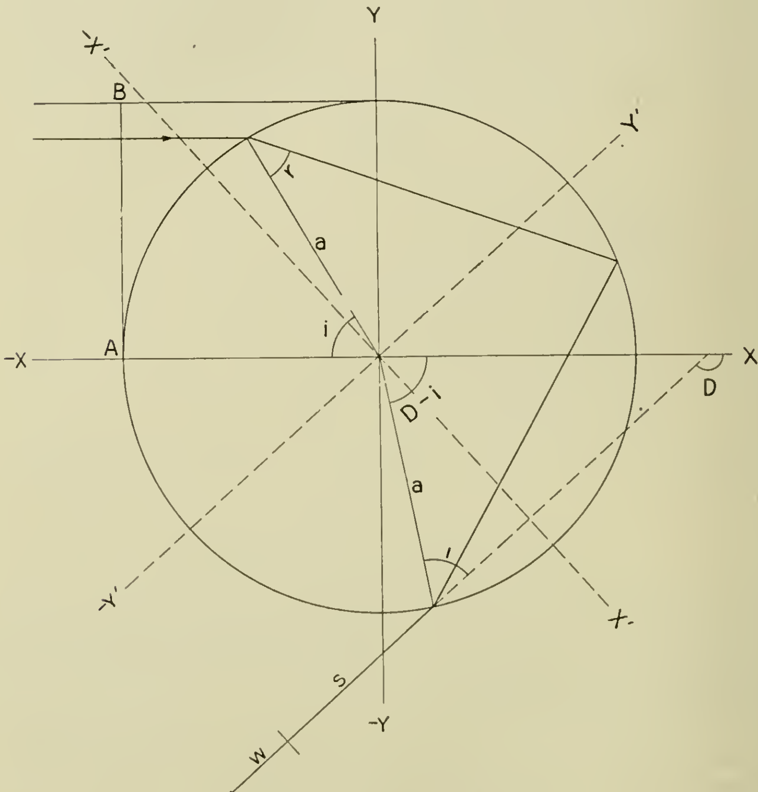

Interference giving supernumerary rainbows.

strictly the arc of a circle, the results they produce at a considerable distance, at the position of the observer, for instance, are qualitatively as though they were.

Let $AIB$, then (Fig. 142), be such a wave front, $I$ being the point of inflection where the front is normal to the ray of minimum deviation. Let the full and dotted curves be opposite phase positions of the resulting cusped wave front. By inspection, it is obvious that soon after leaving the drop all the light must lie on one side of the ray of minimum deviation, thus making the observed angular radius of an arc of any given color slightly less than that of the Descartes ray. It is also obvious that with increasing angular distance from the Descartes ray the two branches of the cusped front are alternately, and with increasing

frequency, in opposite and like phases, thus producing alternate arcs of minimum and maximum brightness, all of smaller angular radius than that of the first maximum, the chief bow, and progressively lying closer and closer together as the radius diminishes, or increases, in the case, respectively, of the primary and the secondary bow.

FIG. 143.




Effect of raindrop on shape of wave front.

These additional maxima, of which several frequently are visible, constitute the familiar supernumerary bows.

*Equation of Portion of Outgoing Wave Front Near Ray of Minimum Deviation.*—In deriving this equation, originally due to Airy,[175] the more direct and elementary method of Wirt-

[175] *Cambridge Phil. Trans.*, vi, 380.

inger[176] will be followed with only such modifications as appear to make for clearness.

Let $AB$ (Fig. 143) be an incident wave front tangent to a raindrop of radius $a$; let $w$ be a small section of the emitted front near the minimum deviation ray—more distant portions of the front need not be considered as they are formed by rays too divergent to produce anything more than a slight general illumination; let $v_1$ be the velocity in air of the light under examination and $v_1\mu$ its velocity in water. Clearly, then, from the constancy of the time interval between corresponding points on the wave fronts,

$$\frac{a(1 - \cos i)}{v_1} + \frac{4\mu a \cos r}{v_1} + \frac{s}{v_1} = T, \text{ a constant.}$$

in which $s$ is the distance between the drop and the corresponding point on $w$; $i$, and $r$, the angles of incidence and refraction, respectively.

Let the completely emitted front be also tangent to the drop, as shown in Fig. 140. Then

$$T = \frac{4\mu a}{v_1}$$

and

$$s = a\left\{4\mu(1 - \cos r) - (1 - \cos i)\right\}$$

Let the centre of the drop be the intersection of coördinates as indicated. Then, if $D$ is the angle of deflection, a point on $w$ is given by the values,

$$x = a \cos (D - i) + s \cos D,$$

and

$$y = - a \sin (D - i) - s \sin D.$$

By turning the coördinates clockwise through the angle $D_1 - \pi/2$, in which $D_1$ is the change in direction of the ray of minimum deviation, the projection angles are correspondingly reduced and the new $y$ axis brought parallel to the emerged Descartes ray. Hence, in terms of the new coördinates, writing $d$ for $D - D_1$,

$$x' = - a \sin (d - i) - s \sin d$$

$$- y' = a \cos (d - i) + s \cos d.$$

[176] Berichte des naturw. medicin. Vereines an der Universität Innsbruck, xxi Jahrg., 1896–97. See also Pernter-Exner, Meteorologische Optik.

But as only rays very near that of minimum deviation need be considered, $d$ is so small that to a sufficiently close approximation,

$$\cos d = 1, \text{ and } \sin d = d.$$

Hence,

$$x' = -\, ad \cos i + a \sin i - sd,$$

and

$$-y' = a \cos i + a\, d \sin i + s.$$

From Fig. 140 it is obvious that the small section, $w$ (Fig. 143), of the emerged wave front is very nearly parallel to the $x'$ axis, and that the $x'$ coördinate, therefore, is extremely sensitive to changes in $y'$, while the $y'$ coördinate is relatively but little affected by the changes in $x'$. Hence, as $d$ is very small, points on $w$ are sufficiently closely given by the expressions,

$$x' = a \sin i$$

and

$$-y' = a \cos i + ad \sin i + a \left\{4\mu\,(1 - \cos r) - (1 - \cos i)\right\}.$$

Let $I$ and $R$ be the angles of incidence and refraction, respectively, corresponding to the minimum deviation, $D_1$, and let

$$i = I + \alpha, \text{ and } r = R + \beta$$

in which and $\beta$ are quite small, since only rays near that of minimum deviation are considered. Further, to make the problem entirely general, let $n$ be the number of internal reflections. Then,

$$x' = a \sin (I + \alpha) = a \sin I + a\alpha \cos I$$

$$-y' = a \cos i + a l \sin i + a \left\{2\,\mu\,(n + 1)\,(1 - \cos r) - (1 - \cos i)\right\}$$

$$= 2\,a \left\{\cos i + \frac{d}{2} \sin i - \mu\,(n + 1) \cos r + \mu\,(n + 1) - \tfrac{1}{2}\right\}.$$

Treating $d$ and $\beta$ as functions of $\alpha$ and developing we get, neglecting powers of $\alpha$ higher than the third,

$$\cos i = \cos (I + \alpha) = \cos I - \alpha \sin I - \frac{\alpha^2}{2} \cos I + \frac{\alpha^3}{6} \sin I + \cdots\cdots$$

$$\frac{d}{2} = \tfrac{1}{2}(D - D_1) = (I + \alpha) - (R + \beta) + \frac{n}{2}\left\{\pi - 2\,(R + \beta)\right\} - \left\{I - R + \frac{n}{2}(\pi - 2\,R)\right\}$$

$$= \alpha - (n + 1)\,\beta = \alpha - (n + 1)\left(\frac{d\beta}{d\alpha}\right)_0 \alpha - (n + 1)\left(\frac{d^2\beta}{d\alpha^2}\right)_0 \frac{\alpha^2}{2} - (n + 1)\left(\frac{d^3\beta}{d\alpha^3}\right)_0 \frac{\alpha^3}{6}$$

Since

$$\frac{d}{2} = \alpha - (n+1)\beta,\ d\frac{d}{2} = d\alpha - (n+1)\,d\beta, \text{ and } \left(\frac{d\beta}{d\alpha}\right)_0 = \frac{1}{n+1},$$

and, since

$$i = I + \alpha, \text{ or } \sin i = \sin I + \alpha \cos I,$$

therefore,

$$\frac{d}{2}\sin i = -(n+1)\left(\frac{d^2\beta}{d\alpha^2}\right)_0 \frac{\alpha^2}{2}\sin I - (n+1)\left(\frac{d^3\beta}{d\alpha^3}\right)_0 \frac{\alpha^3}{6}\sin I - (n+1)\left(\frac{d^2\beta}{d\alpha^2}\right)_0 \frac{\alpha^3}{2}\cos I \text{ - - - -}$$

Finally,

$$\cos r = \cos\left\{R + f(\alpha)\right\} = \cos R + \alpha\frac{d\cos r}{d\alpha} + \frac{\alpha^2}{2}\frac{d^2\cos r}{d\alpha^2} + \frac{\alpha^3}{6}\frac{d^3\cos r}{d\alpha^3} + \text{ - - - - -}$$

But

$$\frac{d\cos r}{d\alpha} = -\sin r\frac{d\beta}{d\alpha} = -\frac{\sin i}{\mu}\frac{d\beta}{d\alpha},$$

$$\frac{d^2\cos r}{d\alpha^2} = -\frac{\cos i}{\mu}\frac{d\beta}{d\alpha} - \frac{\sin i}{\mu}\frac{d^2\beta}{d\alpha^2}$$

$$\frac{d^3\cos r}{d\alpha^3} = \frac{\sin i}{\mu}\frac{d\beta}{d\alpha} - \frac{\cos i}{\mu}\frac{d^2\beta}{d\alpha^2} - \frac{\cos i}{\mu}\frac{d^2\beta}{d\alpha^2} - \frac{\sin i}{\mu}\frac{d^3\beta}{d\alpha^3}$$

At the limits

$$\left(\frac{d\beta}{d\alpha}\right)_0, \left(\frac{d^2\beta}{d\alpha^2}\right)_0, \left(\frac{d^3\beta}{d\alpha^3}\right)_0, \text{ where } i = I,$$

$$-\mu(n+1)\cos r = -\mu(n+1)\cos R - (n+1)\left(\frac{d\beta}{d\alpha}\right)_0\left[-\alpha\sin I - \frac{\alpha^2}{2}\cos I + \frac{\alpha^3}{6}\sin I\right] - (n+1)\left(\frac{d^2\beta}{d\alpha^2}\right)_0\left[-\frac{\alpha^2}{2}\sin I - \frac{\alpha^3}{3}\cos I\right] + (n+1)\left(\frac{d^3\beta}{d\alpha^3}\right)_0\left[\frac{\alpha^3}{6}\sin I\right]$$

Hence, by addition of the above terms, remembering that,

$$\mu\cos R = (n+1)\cos I$$

and that

$$\left(\frac{d\beta}{d\alpha}\right)_0 = \frac{1}{n+1}$$

$$-y' = 2a\left\{1 - (n+1)^2\right\}\cos I - a(n+1)\left(\frac{d^2\beta}{d\alpha^2}\right)_0\frac{\alpha^3}{3}\cos I + a\left\{2\mu(n+1) - 1\right\}$$

Since

$$\sin i = \mu \sin r$$

$$\cos i = \mu \cos r \frac{d\beta}{d\alpha}$$

and

$$- \sin i = - \mu \sin r \left(\frac{d\beta}{d\alpha}\right)^2 + \mu \cos r \left(\frac{d^2\beta}{d\alpha^2}\right)$$

or

$$- \sin I = - \mu \sin R \left(\frac{d\beta}{d\alpha}\right)_0^2 + \mu \cos R \left(\frac{d^2\beta}{d\alpha^2}\right)_0$$

$$= - \frac{\mu \sin R}{(n + 1)^2} + \mu \cos R \left(\frac{d^2\beta}{d\alpha^3}\right)_0$$

But

$$\mu \sin R = \sin I, \text{ and } \mu \cos R = (n + 1) \cos I.$$

Therefore,

$$\left(\frac{d^2\beta}{d\alpha^2}\right)_0 = - \frac{\sin I}{\cos I} \frac{n^2 + 2n}{(n + 1)^3}$$

and

$$- y' = 2a \left[- (n^2 + 2n) \cos I + \mu (n + 1) - \tfrac{1}{2} \right] + a \alpha^3 \frac{n^2 + 2n}{3 (n + 1)^2}$$

$$\sin I, \quad x' = \left[a \sin I\right] + a \alpha \cos I.$$

The first terms in the equations for $x'$ and $y'$ are the coördinates of the point of inflection on the curve $w$. Taking this point as the origin and calling the coördinates $x_1$ and $y_1$ we have for points on $w$,

$$x_1 = a\alpha \cos I$$

$$y_1 = a \alpha^3 \frac{n^2 + 2n}{3 (n + 1)^2} \sin I.$$

But

$$\alpha^3 = \frac{x_1^3}{a^3 \cos^3 I},$$

hence,

$$y_1 = \frac{1}{3a^2} \frac{n^2 + 2n}{(n + 1)^2 \cos^3 I} x_1^3 \sin I.$$

As previously shown,

$$\cos I = \sqrt{\frac{\mu^2 - 1}{n^2 + 2n}},$$

hence,

$$y_1 = \frac{1}{3 a^2} \frac{(n^2 + 2n)^2}{(n + 1)^2 (\mu^2 - 1)} \sqrt{\frac{(n + 1)^2 - \mu^2}{\mu^2 - 1}} x_1^3.$$

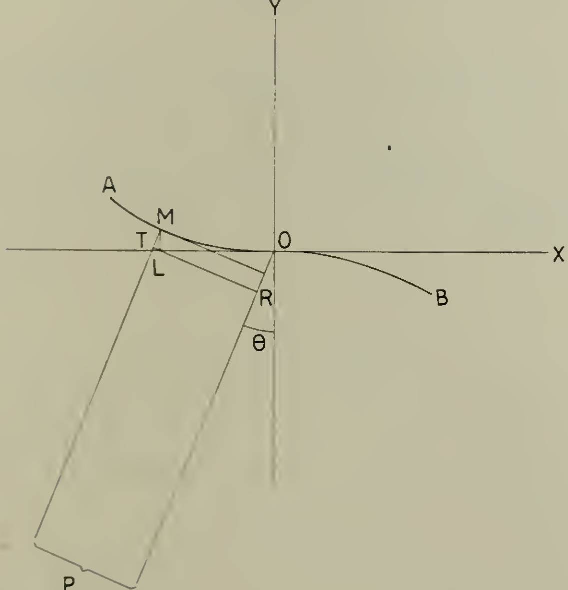
Putting

$$\frac{(n^2 + 2n)^2}{(n + 1)^2 (\mu^2 - 1)} \sqrt{\frac{(n + 1)^2 - \mu^2}{\mu^2 - 1}} = h,$$

$$y_1 = \frac{h}{3a^2} x_1^3.$$

This equation, then, represents a curve very nearly coincident with that portion of the wave front to which the rainbow phenomena are due, and since the effects computed from it substantially agree with those observed, as will be seen presently, it is clear that the approximation thus obtained is sufficient for most, if not all, practical uses: indeed, the assumption that raindrops are perfectly spherical involves, perhaps, a greater error.

FIG. 144.




Variation of intensity with angular distance from ray of minimum deviation.

*Intensity and Its Variation with Angular Distance from the Ray of Minimum Deviation.*—This, too, was first determined by Airy.[177] The following discussion, however, is essentially that of Mascart [178] and Pernter-Exner.[179]

[177] *l. c.*

[178] *Traité d'Optique*, i.

[179] *Meteorologische Optik.*

Let $O$ (Fig. 144) be the point of inflection of an emitted wave front near a drop; let $P$ be a distant point in the direction $\theta$ from the ray of minimum deviation. Then the difference in phase, $\Delta F$, between the light vibrations at $P$, due respectively to an element, $ds$, of the front at $O$ and an equal element at $M$ is given by the equation,

$$\Delta F = 2\pi \frac{OR - MT}{\lambda} = 2\pi \frac{x \sin\theta - y \cos\theta}{\lambda}$$

in which $\lambda$ is the wave-length.

Hence, substituting for $y$ its value, $\frac{hx^3}{3a^2}$, and $dx$ for $ds$, which is allowable over the effective portion of the wave front, the vibration at $P$ is given by the equation,

$$V = k \int \sin 2\pi \left[ \frac{t}{T} - \left( \frac{\frac{hx^3}{3a^2}\cos\theta - x \sin\theta}{\lambda} \right) \right] dx$$

in which $T$ is the period and $k$ the amplitude per unit length of front.

Or, putting

$$\frac{2\pi}{\lambda}\left( \frac{hx^3}{3a^2}\cos\theta - x \sin\theta \right) = \delta$$

$$V = k \int \sin \left( 2\pi \frac{t}{T} - \delta \right) dx$$

$$= k \int \cos \delta \, dx \sin 2\pi \frac{t}{T} - k \int \sin \delta \, dx \cos 2\pi \frac{t}{T}.$$

Since $\cos \delta dx$ and $\sin \delta dx$ appear in this equation as amplitudes it follows, if

$$A = k \int \cos \delta \, dx$$

and

$$B = k \int \sin \delta \, dx$$

that the resultant amplitude $C = \sqrt{A^2 + B^2}$.

But to find $A$ and $B$ it is necessary to integrate the given expressions over the effective portion of the wave front, or through limits that produce essentially the same results. Such limits may be determined as follows:

Let $x$ and $x_1$ be so situated that the difference between their distances from $P$ is $\frac{\lambda}{2}$, and their combined result at that point, therefore, zero. That is, let

$$\frac{h}{3a^2}(x^3_1 - x^3)\cos\theta - (x_1 - x)\sin\theta = \frac{\lambda}{2}$$

or

$$x_1 - x = \frac{\lambda}{2\cos\theta}\cdot\frac{3a^2}{h(x_1^2 + x\,x_1 + x^2) - \tan\theta}$$

Considering the primary bow in which $h$ has its least value, 4.89, nearly, for $\mu = \frac{4}{3}$; assuming the radius, $a$, of a drop to be 1 mm., and writing $\delta x$ for $x_1 - x$, it follows, since $\theta$ is small, that

$$x^2\delta x = .0002 \text{ mm}^3\text{, roughly, for yellow light.}$$

Hence, $\delta x$ decreases rapidly with increase of $x$ (even when $x = .1$ mm., $\delta x = .02$ mm.); and the successive portions of the curve beyond a very short distance from the inversion point, $O$ (Fig. 144), completely neutralize each other, and, therefore, no error will be introduced by integrating between infinity limits instead of between the *unknown* limits of the effective portion of the wave front.

Hence,

$$A = k\int_{-\infty}^{+\infty}\cos\delta\,dx$$

and

$$B = k\int_{-\infty}^{+\infty}\sin\delta\,dx$$

But as the sign of $B$ reverses with that of $x$, while that of $A$ remains unchanged,

$$B = 0$$

and

$$A = 2k\int_0^{\infty}\cos\frac{2\pi}{\lambda}\left(\frac{hx_3}{3a^2}\cos\theta - x\sin\theta\right)dx.$$

Putting

$$\frac{2h}{3\,a^2\,\lambda}x^3\cos\theta = \frac{u^3}{2},$$

from which

$$dx = \left(\frac{3\ a^2\ \lambda}{4h \cos\theta}\right)^{1/3} du,$$

and

$$\frac{2x}{\lambda} \sin\theta = \frac{zu}{2}$$

$$A = 2k \int_0^\infty \left(\frac{3a^2\lambda}{4h\ \cos\theta}\right)^{1/3} \cos\frac{\pi}{2}\ (u^3 - zu)\ du,$$

which is Airy's rainbow integral, in which

$$\frac{\pi}{2}\ (u^3 - zu)\ du = \delta,$$

the difference in phase.

Putting

$$\int_0^\infty \cos\frac{\pi}{2}\ (u^3 - zu)\ du = f(z)$$

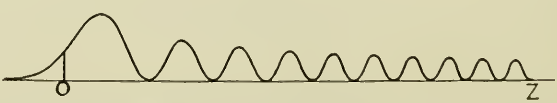
$$A = 2k \left(\frac{3a^2\lambda}{4h \cos\theta}\right)^{1/3} f(z) = M\ f(z),\ \text{say},$$

and the intensity,

$$A^2 = M^2 f^2\ (z).$$

The evaluation of $f(z)$ is not simple, but it has been accomplished through mechanical quadrature by Airy [180] and through development in series by both Airy [181] and Stokes.[182]

FIG. 145.




Periodic changes of intensity of monochromatic light.

The following table and its graph (Fig. 145), both from Pernter-Exner's "Meteorologische Optik," give certain values of $z$ and $f^2(z)$, corresponding to monochromatic light of a particular wave-length and drops of a definite size.

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[180] *Cambridge Phil. Trans.*, vi, p. 379.

[181] *Cambridge Phil. Trans.*, viii, p. 595.

[182] *Cambridge Phil. Trans.*, ix, part i.

*Values of $F^2(Z)$ for Different Values of Z.*

| $z$ | $f^2(z)$ | $z$ | $f^2(z)$ | $z$ | $f^2(z)$ |
|---|---|---|---|---|---|
| −2.0 | 0.006 | 3.4 | 0.609 | 8.8 | 0.189 |
| −1.8 | 0.011 | 3.6 | 0.586 | 9.0 | 0.373 |
| −1.6 | 0.018 | 3.8 | 0.436 | 9.2 | 0.320 |
| −1.4 | 0.030 | 4.0 | 0.225 | 9.4 | 0.100 |
| −1.2 | 0.048 | 4.2 | 0.051 | 9.6 | 0.001 |
| −1.0 | 0.074 | 4.4 | 0.003 | 9.8 | 0.054 |
| −0.8 | 0.113 | 4.6 | 0.104 | 10.0 | 0.240 |
| −0.6 | 0.168 | 4.8 | 0.297 | 10.2 | 0.360 |
| −0.4 | 0.239 | 5.0 | 0.465 | 10.4 | 0.220 |
| −0.2 | 0.331 | 5.2 | 0.501 | 10.6 | 0.022 |
| 0.0 | 0.443 | 5.4 | 0.379 | 10.8 | 0.013 |
| 0.2 | 0.571 | 5.6 | 0.172 | 11.0 | 0.170 |
| 0.4 | 0.706 | 5.8 | 0.014 | 11.2 | 0.338 |
| 0.6 | 0.836 | 6.0 | 0.022 | 11.4 | 0.270 |
| 0.8 | 0.941 | 6.2 | 0.174 | 11.6 | 0.050 |
| 1.0 | 1.001 | 6.4 | 0.370 | 11.8 | 0.004 |
| 1.2 | 0.996 | 6.6 | 0.450 | 12.0 | 0.140 |
| 1.4 | 0.914 | 6.8 | 0.353 | 12.2 | 0.320 |
| 1.6 | 0.758 | 7.0 | 0.141 | 12.4 | 0.256 |
| 1.8 | 0.547 | 7.2 | 0.010 | 12.6 | 0.045 |
| 2.0 | 0.319 | 7.4 | 0.046 | 12.8 | 0.006 |
| 2.2 | 0.125 | 7.6 | 0.230 | 13.0 | 0.136 |
| 2.4 | 0.014 | 7.8 | 0.394 | 13.2 | 0.314 |
| 2.6 | 0.016 | 8.0 | 0.363 | 13.4 | 0.202 |
| 2.8 | 0.131 | 8.2 | 0.150 | 13.6 | 0.013 |
| 3.0 | 0.317 | 8.4 | 0.010 | .... | ..... |
| 3.2 | 0.502 | 8.6 | 0.038 | .... | ..... |

*Maxima and Minima.*

| Maxima | $z$ | $f^2(z)$ | Minima | $z$ |
|---|---|---|---|---|
| 1. | 1.0845 | 1.005 | 1. | 2.4955 |
| 2. | 3.4669 | 0.615 | 2. | 4.3631 |
| 3. | 5.1446 | 0.510 | 3. | 5.8922 |
| 4. | 6.5782 | 0.450 | 4. | 7.2436 |
| 5. | 7.8685 | 0.412 | 5. | 8.4788 |
| 6. | 9.0599 | 0.384 | 6. | 9.6300 |
| 7. | 10.1774 | 0.362 | 7. | 10.7161 |
| 8. | 11.2364 | 0.345 | 8. | 11.7496 |
| 9. | 12.2475 | 0.330 | 9. | 12.7395 |
| 10. | 13.2185 | 0.318 | 10. | 13.6924 |

It will be noticed that the first maximum does not coincide with $z = 0$, nor, therefore, with $\theta = 0$, the direction of the ray of minimum deviation; that the intensity of the first maximum, corresponding to a principal bow, is much the greatest; and that the succeeding maxima, corresponding to the supernumerary

bows, and also the angular intervals between successive maxima, continuously decrease, at a decreasing rate, with the increase of $\theta$.

*Distribution of Colors in the Rainbow.*—The above discussion of the distribution of light intensity applies, as stated, to monochromatic light. When the source of light simultaneously emits radiations of various wave-lengths, as does the sun, a corresponding number of bows, each consisting of a sequence of maxima and minima, are partially superimposed on each other. In this way different colors are mixed, and thus the familiar polychromatic rainbow produced.

The particular mixing of colors that obtains is the result of several coöperating causes. Thus the distribution of intensity, as illustrated by Fig. 145, depends on phase difference, as given by the expression,

$$2\pi\,\frac{\frac{h}{3a^2}\,x^3\cos\theta - x\sin\theta}{\lambda}.$$

The angular intervals between maxima, say, increase, therefore, with $\lambda$, and, consequently, coincident distribution of the intensities of any two colors is impossible. Again, since the direction of the ray of minimum deviation varies with the refractive index, as already explained, and that in turn with the wave-length or color, it follows that the direction of the zero point on the intensity curve, near which the first maximum lies, correspondingly varies. Obviously, then, these two causes together produce all sorts of color mixings that in turn arouse widely varied sensations.

To determine, however, just what color mixtures are induced by drops of any given size, it obviously is necessary to express the values of the abscissa, $z$, of the intensity curve (Fig. 145) in terms of angular deviation from the corresponding principal ray, since the direction of each such ray fixes the position of origin of its particular curve.

Let, then, as before,

$$\frac{z\,u}{2} = \frac{2\,x}{\lambda}\sin\theta$$

or

$$z^3 = \left(\frac{4\sin\theta}{\lambda}\,\frac{x}{u}\right)^3$$

Also, as before, let

$$\left(\frac{x}{u}\right)^3 = \frac{3a^2\lambda}{4\,h\cos\theta}$$

hence,

$$z^3 = \frac{48\ a^2}{h\ \lambda^2}\sin^2\theta\ \tan\theta .$$

But whatever the value of $\theta$ from 0° to 30°

$$\frac{\sin^2\theta\ \tan\theta}{\theta^3} = 1, \text{ to within } .0055.$$

Hence, approximately,

$$z^3 = \frac{48\ a^2}{h\ \lambda^2}\ \theta^3,$$

or

$$\theta = \frac{z}{2a^{\frac{2}{3}}}\left(\frac{h\ \lambda^2}{6}\right)^{\frac{1}{3}}$$

From this equation it appears that the angular distance between any two successive intensity maxima varies directly as the cube root of the square of the wave-length and inversely as the cube root of the square of the diameter, or other linear dimension of the parent drop. That is, this interval is greater for red light than for blue, and greater for small drops than for large ones.

The following table, copied with slight changes, from Pernter-Exner's "Meteorologische Optik," gives the values of $\theta$ in minutes of arc per 0.2 $z$, for lights of different wave-length and drops of different size.

*Angle in Minutes per 0.2 z, Primary Bow.*

| $a$ = in microns | 5 | 10 | 15 | 20 | 25 | 30 | 40 | 50 | 100 | 150 | 250 | 500 | 1000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| λ, in microns | Angle in minutes | | | | | | | | | | | | |
| .687 | 85.8 | 54.0 | 41.2 | 34.0 | 29.3 | 26.0 | 21.4 | 18.5 | 11.7 | 8.9 | 6.32 | 3.98 | 2.51 |
| .656 | 83.0 | 52.3 | 39.9 | 32.9 | 28.4 | 25.1 | 20.7 | 18.0 | 11.0 | 8.6 | 6.10 | 3.84 | 2.43 |
| .589 | 77.0 | 48.5 | 37.0 | 30.5 | 26.4 | 23.3 | 19.3 | 16.6 | 10.5 | 7.9 | 5.67 | 3.57 | 2.26 |
| .527 | 71.2 | 44.9 | 34.2 | 28.2 | 24.4 | 21.6 | 17.8 | 15.4 | 9.6 | 7.4 | 5.25 | 3.31 | 2.10 |
| .494 | 68.1 | 42.8 | 32.6 | 27.0 | 23.1 | 20.6 | 17.0 | 14.7 | 9.3 | 7.1 | 5.02 | 3.15 | 2.03 |
| .486 | 67.2 | 42.3 | 32.3 | 26.7 | 22.8 | 20.3 | 16.8 | 14.5 | 9.1 | 7.0 | 4.94 | 3.12 | 1.99 |
| .449 | 63.4 | 40.0 | 30.5 | 25.2 | 21.7 | 19.2 | 15.9 | 13.7 | 8.6 | 6.6 | 4.67 | 2.93 | 1.88 |
| .431 | 51.5 | 38.8 | 29.6 | 24.4 | 21.0 | 18.6 | 15.4 | 13.3 | 8.3 | 6.4 | 4.53 | 2.87 | 1.82 |

By the aid of this table; a table of intensity distribution, $M^2f^2(z)$, along the coördinate $z$; and the following relative intensities,

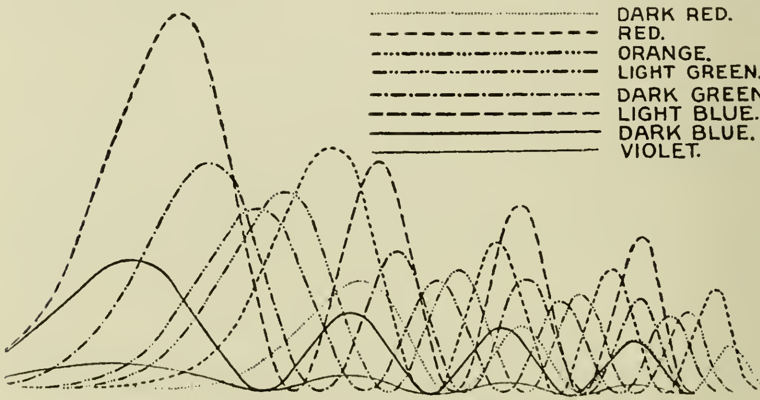
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| λ | .687 | .656 | .589 | .527 | .494 | .486 | .449 | .431 |
| I | 20 | 86 | 250 | 152 | 121 | 134 | 163 | 74 |

Pernter has constructed Figs. 146 and 147 that show the intensity distributions of these several colors due to drops of .5 mm. and .05 mm. radius, respectively.

It still remains to determine the color at any particular point at which the relative intensities of the several colors are known. This can be done by the aid of Maxwell's [183] color triangle, as explained in detail by Pernter.[184]

*Relation of size of Drop and Wave-length to Intensity.*—Since the Airy expression for the amplitude of the vibration produced at a distant point by the effective portion of the emitted wave front involves the factor, $(\lambda a^2)^{1/3}$, it is evident that the cor-

FIG. 146.




Distributions of colors by drops of 0.5 mm. radius.

responding intensity, which is proportional to the square of the amplitude, will be proportional to $(\lambda a^2)^{2/3}$. This, however, is based on the assumption that the effective light from the drop comes strictly from the *line* of a great circle. As a matter of fact, it actually comes from a narrow belt whose effective angular width, as measured from the centre of the drop, is inversely proportional to the curvature, or directly to the radius $a$, and inversely proportional to the wave-length.[185] Hence, the actual intensity is proportional to $a$.

[183] *Trans. Roy. Soc.*, p. 57, 1860.

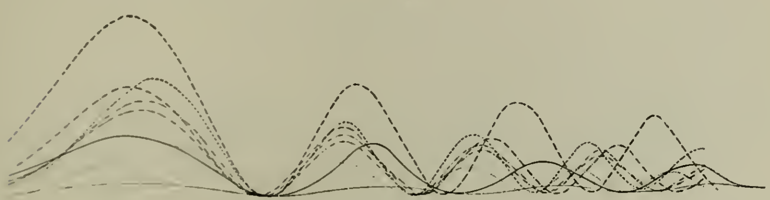
[184] *Meteorologische Optik.*

[185] Mascart, C. R., V. 115, p. 453, 1892.

A larger fraction of the short wave-length light is effective, therefore, than of the long. Further, the rainbow bands produced by very small droplets are not only broad, as previously explained, but also feeble, and as their colors necessarily are faint they frequently are not distinguished—the bow appearing as a mere white band.

*Popular Questions About the Rainbow.*—A few popular questions about the rainbow need perhaps to be answered. "What is the rainbow's distance?" In the sense of its proximate origin, the drops that produce it, it is nearby or far away, according to their respective distances, and thus extends from the closest to the farthest illuminated drops along the elements of the rainbow cone. Indeed, the rainbow may be regarded as consisting of coaxial, hollow conical beams of light of different colors seen edgewise from the vertex, and thus having great depth or extent in the line of sight.

FIG. 147.



Distributions of colors by drops of 0.05 mm. radius.

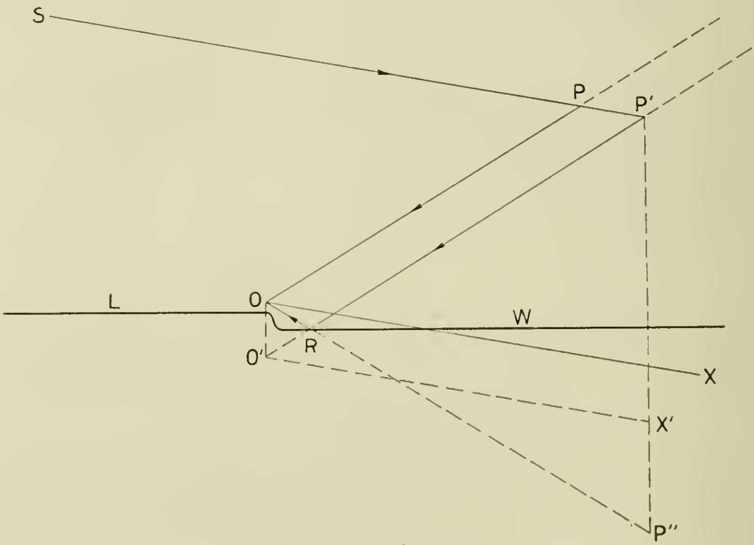
"Why is the rainbow so frequently seen during summer and so seldom during winter?" Its formation requires the coexistence of rain and sunshine, a condition that often occurs during local convectional showers but rarely during a general cyclonic storm, and as the former are characteristic of summer and the latter of winter, it follows that the occurrence of the rainbow correspondingly varies with the seasons.

"Why are rainbows so rarely seen at noon?" As above explained, the centre of the rainbow's circle is angularly as far below the level of the observer as the sun is above it, hence no portion of the bow can be seen (except from an elevation) when its angular radius is less than the elevation of the sun above the horizon. Now, during summer, the rainbow season, the elevation of the sun at noon is nearly everywhere greater than 42°, the angular radius of the primary bow, or even 51°, the radius of the

secondary bow. A rainbow at noon, therefore, is, except for very high latitudes, an impossible summer phenomenon, and, of course, a rare winter one, for reasons given above, even where possible.

"Do two people ever see the same rainbow?" Theory teaches, and ordinary experience shows, that as the observer remains stationary or moves, so also, other things being equal, does his rainbow. If then, two observers initially close together should move in opposite directions, each would find his rainbow responding in the same sense as his shadow, and presently the

FIG. 148.




Reflected rainbow.

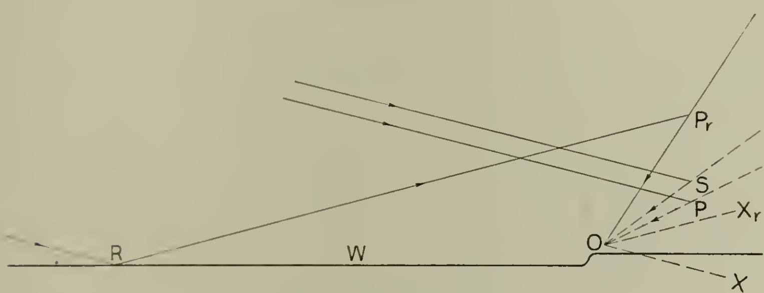
positions and, therefore, the identity of the two bows would become unquestionably different, from which it follows that as the eyes of two observers must always be separated by a greater or less distance their bows must also be correspondingly separated and different—different in the sense that they have different positions and are produced by different drops. In short, since the rainbow is a special distribution of colors (produced in a particular way) with reference to a definite point—the eye of the observer—and as no single distribution (other than uniform and infinite) can be the same for two separate points, it follows that two observers do not and cannot see the same rainbow.

"Can one see the same rainbow by reflection that he sees directly?" An object seen by reflection in a plane surface is seen by the same rays that but for the mirror would have focussed to a point on a line normal to it from the eye and as far back of it as the eye is in front. But, as just explained, the bows appropriate to two different points are produced by different drops; hence, a bow seen by reflection is not the same as the one seen directly.

*Reflected Rainbows.*—Since rainbows occasionally are seen reflected in smooth bodies of water they deserve, perhaps, a somewhat fuller explanation than that just given.

Let an observer be at $O$ (Fig. 148). Under proper conditions of rain and sunshine he will see directly a primary bow due to drops on the surface of a cone formed by rotating $OP$ about

FIG. 149.




Reflection rainbow.

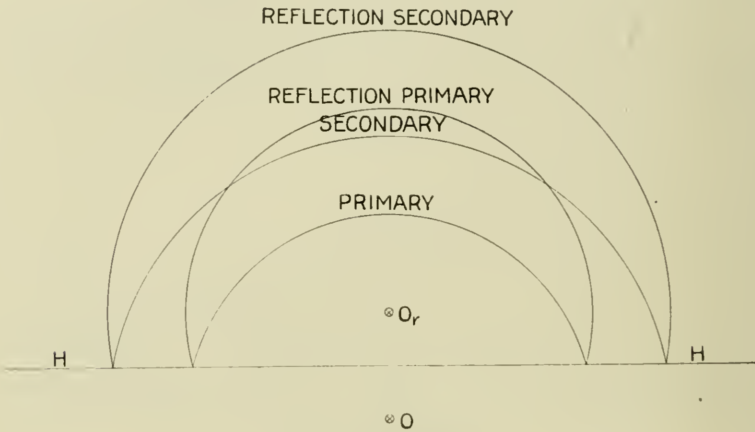
$OX$, parallel to $SP$, keeping the angle, $POX$, roughly 42°, constant; and by reflection in the surface of the water, $W$, another primary bow due to drops on the surface of a different cone, one formed by rotating $O'P'$ about $O'X'$, also parallel to $SP$, keeping the angle $P'O'X'$ constant. The bow seen by reflection necessarily will appear upside down, $P'$ at $P''$, etc. The arc of the bow seen by reflection obviously (from the figure) will be less than that of the bow seen directly, and for that reason is likely to appear flatter.

*Reflection Rainbows.*—A reflection rainbow is here defined as one due to reflection of the light source, the sun, usually, but itself seen directly.

Let the observer be at $O$ (Fig. 149) with the sun and a smooth surface of water, $W$, at his back and illuminated rain in front. The direct sunshine will give a primary and a secondary bow

along the elements of cones formed by rotating $OP$ and $OS$, respectively, about the common axis, $OX$, parallel to the incident rays, keeping the angles $POX$ and $SOX$ constant; while the reflected light will give a primary bow along the elements of a cone formed by the rotation of $OP_r$ about the axis $OX_r$ ($OX_r$ parallel to $RP_r$), keeping the angle $P_rOX_r$ constant, and equal to $POX$. Reflection bows of higher orders than that of the primary are likely to be too faint to be seen.

FIG. 150.




Direct and reflection rainbows.

The angular elevation of the centre (axis really) of the reflection bows clearly is equal to the angular depression of the centre of the direct bows. Hence, the direct and the reflection bows of the same order intersect on the observer's level, as shown in Fig. 150.

(*To be Continued.*)

## REFRACTORY MATERIALS AND HIGH TEMPERATURE MEASUREMENTS.*

BY

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### THE TEMPERATURE SCALE.

BEFORE we consider the measurement of high temperatures, it is important to know just what is meant by temperature. There are a number of physical terms, including "energy," "force," "mass," and "temperature," the meanings of which are generally well enough understood for most purposes, but the precise definition of which is not easy. People sometimes think of temperature as being defined by the expansion of mercury in a thermometer, as by dividing the stem of a mercury thermometer between the freezing point of water and the boiling point into equal spaces. Temperatures defined in such a way would depend upon the kind of glass of which the thermometer was made, and if some other liquid than mercury were used the scale would be still different. The definition would be very arbitrary. There are some very important general principles of physics involving temperature which are true if temperature is properly defined, but would not be true if any such arbitrary definition were used.

If we start with the merely qualitative conception of temperature that we obtain through our senses, we may form a satisfactory quantitative definition if we employ the observation that, in the words of Clausius, "it is impossible for a self-acting machine, unaided by any external agency, to convey heat from one body to another at a higher temperature." By the employment of this principle and that of the conservation of energy, it has been demonstrated that in any reversible cyclic process operating between, $T_1$, and a lower temperature, $T_2$, the ratio $\frac{Q_1}{Q_2}$ of the quantity of heat absorbed at the higher temperature to that given out at the lower depends only upon $T_1$ and $T_2$. Lord Kelvin has proposed that absolute temperature be so defined that

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

* Presented at a meeting of the Section of Physics and Chemistry held Tuesday, February 14, 1918.

This is a single equation involving two temperatures, and to make the definition complete, we specify arbitrarily that the difference between the boiling point of water under a pressure of one standard atmosphere and the freezing point shall be 100°. This gives us the absolute temperature in centigrade degrees, while the ordinary centigrade scale in which the freezing point is taken arbitrarily as zero differs from the absolute scale by the difference between the absolute zero and the freezing point, which is 273° C.

The definition here presented employs the conception of a reversible thermodynamic process. The restriction to a "reversible" process is important. By this is meant a process the direction of which can be reversed by infinitesimal changes in the applied forces. For example, if a gas were compressed in a cylinder and there were no transfer of heat to or from the gas and friction could be eliminated, the force applied to the piston to produce slow compression would need to be only infinitesimally more than the resisting force exerted by the gas at that particular stage in the compression, and an infinitesimal diminution in applied force would be sufficient to reverse the action at that stage. Practically, we cannot entirely eliminate the friction of the piston, nor perfectly control the transfer of heat, but this results merely from defects in our machine, and does not depend upon properties of the gas, and by making allowance for these imperfections we can learn the influence of a reversible process upon the gas.

An example of an irreversible process is presented by a gas mixture in which combustion is taking place. Our definition of temperature does not apply to a flame; a flame has no temperature. This fact, which is not always realized, illustrates the importance of the careful consideration of definitions, and is one reason why I have discussed the definition here. Perhaps some other definition of temperature could be formed which would be applicable to a flame, but I am not aware that any consistent one has been developed. We may think of the temperature of the flame as the temperature which a solid object placed in it will acquire; but this temperature depends upon various conditions, including the loss of heat from the solid by conduction and radiation, and even if we can prevent such loss of heat it depends upon the nature of the solid, for the solid may have a marked

influence upon the rate of combustion, and probably has some influence in any case. When a flame contains solid particles of carbon, as a yellow gas flame does, these solid particles have a temperature and it can be measured, but it does not represent the temperature of the gaseous part of the flame. For practical purposes, we do not want to know the real temperatures of flames, but only that which they will impart to solids or liquids, and this, of course, can be determined, but it depends upon conditions.

The definition of temperature which has been presented, which may be called the thermodynamic definition, is equivalent to that in terms of the expansion of an ideal gas, that is, one in which the product of pressure and volume is proportional to absolute temperature, and which does not change temperature when it expands without doing work. No such gas exists, but if we use a real gas, a determination of certain physical constants of the gas and the use of the laws of thermodynamics enable us to calculate the difference between the apparent temperature indicated by the expansion of the gas and the true thermodynamic temperature.

The International Committee on Weights and Measures adopted as the standard thermometer scale that defined by the constant-volume hydrogen thermometer. Since hydrogen approaches closely the condition of a perfect gas, the difference between this scale and the thermodynamic scale is very small.

Gas thermometers are of value as primary standards, but their use requires a great deal of care, and they are not well adapted to routine work. At high temperatures they are especially limited by the circumstance that there are no materials from which the thermometer bulbs can be made which resist temperatures above certain limits without permitting the gas to leak out, and without undergoing permanent deformation. At high temperatures nitrogen has been used in preference to hydrogen because nitrogen does not leak out as fast. Nitrogen thermometers have been used at temperatures up to about 1600° centigrade. They are used for the calibration of pyrometers of other types, and especially for the determination of standard temperatures, most of them the melting points of pure substances, which temperatures can be readily reproduced and serve as practical standards.

THERMOCOUPLES.

Of the pyrometers used practically, thermocouples are the most numerous. A thermocouple consists essentially of two wires of different materials joined end to end. If the junction is heated, a small electromotive force is produced, which may be measured by an electrical instrument attached to the other ends of the wires. The electromotive force depends not only upon the temperature of the hot junction, but also upon the temperatures of the other junctions in the circuit, and either the cold junctions must be kept at constant temperature, or their temperatures must be measured and a suitable allowance made. The metals of the couple must, of course, be able to withstand the temperatures to be measured, and for accurate work they must not change under the action of heat, and they must be uniform. For high temperatures the best couples known are those having one wire made of pure platinum, the other of an alloy of platinum with about 10 per cent. of rhodium. They are, of course, rather expensive. The chief difficulty in their use arises from the necessity of protecting the platinum very well from contamination, which causes a change in electromotive force and an error in reading. Any metal, even metal vapor, is injurious. A reducing atmosphere is also very injurious, perhaps because it introduces silicon into the platinum by reduction of some of the silica compounds usually present in the furnace used. The platinum couples are usually protected by air-tight procelain tubes.

When the temperature to be measured is not very high, cheaper couples made of base metals may be used. For instance, for low temperatures couples made of copper and constantan are useful, constantan being an alloy of copper and nickel; for higher temperatures iron and constantan, and various alloys containing nickel, iron, chromium and aluminum are used. Base metal couples cannot well be used above about 1100° or 1200° C.

The electromotive force is commonly measured by a galvanometer, the scale of which may be graduated to read temperature directly. The galvanometer should have a high resistance, else its indication will depend too much upon the resistance of the couple, which depends upon how much of the couple is heated. For the most accurate work a potentiometer is employed.

Before a thermocouple is used a calibration must usually be made to find the relation between the electromotive force of the

couple and the temperature. This cannot be calculated from any known theoretical relations. If several couples are made from a stock of wire drawn from the same ingot, one calibration on that lot of wire may be sufficient for practical purposes, but in the case of most metals it is difficult to obtain wire that is sufficiently uniform so that couples made from different portions of it by joining to uniform wire of another material will give the same electromotive force at the same temperature.

Couples may be calibrated by means of known melting points or boiling points. The melting points of copper, silver, antimony, zinc and lead are commonly employed. The metal is melted in a crucible of some material that will not contaminate it, the couple is placed inside a protecting tube and immersed deep in the metal, the metal is allowed to cool slowly and the electromotive forces measured at definite times are observed. While the metal is freezing the electromotive force remains nearly stationary and the value then observed corresponds to the melting point of the metal.

### RESISTANCE THERMOMETERS.

This form of pyrometer depends upon the change of resistance of a metal with temperature. The metal used is almost always platinum. They are not used to quite so high temperatures as platinum thermocouples, partly because to have enough resistance, the wire must be rather fine, and is therefore more easily influenced by contamination. They are capable of detecting very small changes of temperature, which is important for special purposes.

The current which measures the resistance of the platinum must be carried to it by leads, and it is necessary to eliminate the resistance of the leads from the resistance measured, since this resistance depends upon the distribution of temperature along the leads. This resistance may be eliminated by either of two methods, known as the three-lead method, and the four-lead method. In the three-lead method, two leads are used on one side of the platinum resistance, and if the leads are in all respects the same, and if the resistance of the two in series is subtracted from the resistance through the platinum with a lead at each end, the result is the resistance of the platinum. The four-lead method is the most reliable for accurate work. In this method two leads carry a current through the platinum resistance, while the other

two serve for the measurement of the difference in potential between the two ends of the resistance.

The platinum wire is commonly wound on mica. It should be wound in such a way that the inequality in the expansion of platinum and the supporting material does not put a strain on the platinum, for this would change its resistance.

Resistance thermometers, like thermocouples, must be calibrated against known temperatures. The boiling points of sulphur, naphthalene and water, and the melting point of ice are commonly used.

### OPTICAL AND RADIATION PYROMETERS.

The pyrometers so far described all have parts that must be put into the place where the temperature is to be measured. When we need to measure extremely high temperatures, say temperatures above 1500° C., we cannot find materials suitable for the purpose that are sufficiently permanent at high temperatures, but we can then determine the temperatures by a study of the light and heat radiation emitted.

The intensities of the radiations of various wave lengths emitted depend not only upon the temperature but also upon the material that emits the radiation. But fortunately there are certain conditions that give a kind of radiation which depends upon the temperature only. If a closed vessel of any solid material is heated to a uniform temperature the nature of the radiation inside the vessel depends only upon the temperature and not upon the material. Such a vessel is commonly called a " black body." If a hole is made in the wall of the vessel that is small relative to the dimensions of the vessel, the radiation within the vessel is changed only a little, and the radiation that comes out of the hole is very nearly " black body radiation." This radiation is of all wave lengths, both visible and invisible. The influence of temperature upon its composition is known, and is expressed by the following equations:

$$E = \sigma T^4 \qquad \text{Stefan and Boltzmann}$$

$$I = \frac{C_1}{\lambda^5 \left(e^{\frac{C_2}{\lambda T}} - 1\right)} \qquad \text{Planck}$$

$$I = \frac{C_1}{\lambda^5 e^{\frac{C_2}{\lambda T}}} \qquad \text{Wien}$$

$E$ = total energy radiated from unit area in unit time.
$\lambda$ = wave length.
$I$ = energy per unit range of wave length radiated from unit area in unit time.
$T$ = absolute thermodynamic temperature.
$e$ = base of Napierian logarithms.
$\sigma$, $C_1$, $C_2$ = universal constants.

When the wave length is expressed in centimetres, and the area in square centimetres, and the gram calorie, second and centigrade degree are used, the values of these constants are:

$$\sigma = 1.28 \times 10^{-12}$$
$$C_1 = 8.8 \times 10^{-13}$$
$$C_2 = 1.445$$

The Stefan-Boltzmann law is strictly correct. It was obtained experimentally by Stefan and was later proved on the basis of thermodynamics by Boltzmann.

The Planck law agrees with observation, and Planck and others have presented theoretical demonstrations. These demonstrations have not been founded upon such unquestionable principles as those underlying the Stefan-Boltzmann law, and have given rise to much discussion among physicists; but the weight of observational and theoretical evidence is such that the relation may be safely employed.

The Wien law, which was published before the Planck law, is not strictly correct; but its errors are large only for long wave lengths in the infra-red radiation, while for visible light the difference between this law and Planck's is below the limits of observation. It is, therefore, employed in optical pyrometry, and leads to much simpler calculations than the Planck law.

Each of these laws gives the radiation from the black body. There is also radiation from the surroundings or from the observing instrument to the black body, and the net transfer of energy is the difference between the two; but in pyrometry the latter effect is negligible.

There are two important classes of pyrometers employed at very high temperatures; those that depend upon the intensity of visible light, called optical pyrometers, and those that depend upon the total radiant energy of all wave lengths, commonly called radiation pyrometers.

The Holborn-Kurlbaum or Morse optical pyrometer h been employed in the most accurate measurements of very temperatures. It consists essentially of a telescope, which ma have little or no magnifying power, with a small filament lamp in the focal plane of the eye-piece, which is covered with a piece of red glass of a kind transmitting as nearly as possible monochromatic light. Upon looking into the instrument one sees an image of the object upon which it is sighted, and over this image the lamp filament. The current in the filament is varied by means of a variable resistance until the end of the filament has the same brightness as the field, when it becomes nearly or quite invisible. The current is then measured. The instrument is calibrated by observing known temperatures and forming a curve or equation giving the relation between current and temperature. The lamp must not be heated to as high a temperature as that at which it would be operated for illuminating purposes, because at such a temperature its temperature-current relation would change with time. When it is necessary to measure higher temperatures, a black absorption glass is placed between the instrument and the heated object, and the apparent temperature observed through the glass is measured. The glass may be calibrated by observing through it an object at a temperature low enough to be also observed directly. Then, if

$T_1$ = known temperature
$T_2$ = unknown temperature
$T_3$, $T_4$ = apparent temperatures when $T_1$ and $T_2$, respectively, are observed through the glass,

all temperatures being on the absolute scale, the unknown temperature can be calculated from the relation

$$\frac{1}{T_4} - \frac{1}{T_2} = \frac{1}{T_3} - \frac{1}{T_1},$$

which can be deduced from the Wien law. The quantity $\frac{1}{T_3} - \frac{1}{T_1}$ is a constant characteristic of the absorption glass for the wave length used. No knowledge of the radiation constants or the wave length is required when this method is employed. By using a sufficiently dark glass it is possible to measure the highest temperature that can be produced.

In the Wanner of Scimatco optical pyrometer the field is divided into two halves, each of which is uniformly illuminated, one by the object upon which the instrument is sighted, the other

...san electric lamp, which is operated at a constant brightness ...ni asional comparison with an amyl acetate flame. A system of prisms permits the transmission only of light in a portion of the red end of the visible spectrum and the employment of two polarizing prisms, one fixed, the other movable, permits the variation of the intensities of the two parts of the field until they match. The angle to which the movable prism has been turned indicates the temperature.

There are a number of optical pyrometers in which the field is divided into two parts, one illuminated by the heated object, the other by a standard source of light, the two parts being brought to the same brightness by placing some variable absorbing device in the path of the more intense source of light.

In radiation pyrometers, the radiant heat is caused to fall upon one junction of a thermocouple, which is connected to a galvanometer. In the Féry type the radiation is converged by a concave mirror onto a thermocouple exposed under an opening in a small shielding box. The radiation entering is limited by this opening. In the Thwing type, the radiation is limited by a diaphragm at the front of the instrument. Radiation pyrometers give good results with suitable precautions, but they are somewhat influenced, especially in the Féry type, by stray heat, which may reach the thermocouple otherwise than by direct radiation.

Both optical and radiation pyrometers are usually calibrated to read correctly when sighted upon a black body. The interior of a furnace fairly uniformly heated usually approximates black body conditions, but it is often required to measure the temperature of objects in the open, for example, red-hot billets of metal in the process of rolling. In such cases it is necessary to know the emissivity of the particular material observed, that is, the ratio of the intensity of the radiation it emits to that emitted by a black body, or to calibrate the pyrometer by comparing observations made with it with the temperature of the material as measured in some other way, as by thermocouples. The emissivity is a function of both temperature and wave length.

### PYROMETRIC CONES.

Pyrometric "cones" are employed for temperature control in many industries. They consist of slender pyramidal molded forms of various materials, which are set up in a slightly inclined

position in a base of clay or other material, and inserted in the furnace the temperature of which is to be controlled. When a cone has softened sufficiently to bend over until its tip touches the support, the temperature corresponding to that cone is considered to have been reached. A series of cones corresponding to temperatures at intervals of about 20° C. is employed.

Cones are not adapted to the accurate measurement of temperature, since their falling over depends not only upon the temperature but also upon the length of time of heating. It is, therefore, not advisable to attempt to correlate definite temperatures with the cone numbers. However, they are very useful in the control of many industrial operations when they are used under nearly constant conditions and when it has been found by trial that the operation of a furnace at a certain cone number gives satisfactory results.

### TEMPERATURE TABLE.

Some of the more important or more interesting high temperatures are shown in the table. The very high temperatures, except those of the stars, have been measured with optical or radiation pyrometers. The determination of the surface temperature of the sun is based upon the assumption that it radiates like a black body. The estimates of the surface temperatures of the stars have been based upon observations of the distribution of energy in their spectra. These estimates are quite uncertain. The temperatures in bold-face type are accurately known and are employed as fixed points in the calibration of pyrometers.

| | Centigrade Degrees |
|---|---|
| Stars (at surface) | up to about 20,000 |
| Sun (at surface) | 6,000 |
| Highest temperature yet produced artificially | 6,000 |
| Carbon arc | 3,800 |
| Tungsten melts | 3,400 |
| Magnesia melts | 2,800 |
| Lime melts | 2,570 |
| Iron boils | 2,450 |
| Copper boils | 2,300 |
| Alumina melts | 2,050 |
| Platinum melts | 1,755 |
| Fireclay melts | 1,560 to 1,725 |
| Palladium melts | 1,550 |
| Pure iron melts | 1,530 |

| | Centigrade Degrees |
|---|---|
| Nickel melts | 1,452 |
| Cast iron melts | 1,100 to 1,250 |
| Copper melts | 1,083 |
| Gold melts | 1,063 |
| Silver melts | 961 |
| Antimony melts | 630 |
| Sulphur boils | 444.6 |
| Zinc melts | 419 |
| Tin melts | 232 |

### MELTING POINTS.

One of the most important properties of a refractory material is its melting point. We are accustomed to thinking of a melting point as a temperature at which a substance changes from a condition in which it does not flow perceptibly under its own weight to a condition in which it flows readily. Most pure substances have melting points that are quite definite and unmistakable, but with some materials this is not the case. For example, when glass is heated, the transition from its ordinary condition to a distinctly fluid condition is a very gradual one and occupies a range of several hundred degrees. Some other substances which possess perfectly definite temperatures of transition to a fluid phase, undergo changes resembling fusion at lower temperatures. Solids in general become softer when heated; they may become so soft as to yield to their own surface tension, with the result that sharp corners are rounded off. Rutile, in its natural slightly impure condition, melts at about 1700° C. The melting point is very definite, there being a sharp transition from a rather soft solid to a liquid of low viscosity, with a considerable absorption of heat. Yet at temperatures 100 degrees or more below the melting point, corners are rounded off and small particles become sintered together. The sintering of clay is probably a similar phenomenon of surface tension. Clay exists generally in the form of extremely fine particles, its unusually slight solubility in water accounting for this condition. Fine particles are more readily united by surface tension than large ones.

A melting point can be precisely defined, in such a manner that it corresponds to a real discontinuity in the nature of the substance, only as the temperature at which a crystalline or anisotropic phase and an amorphous or isotropic phase of the same composition can exist in contact in equilibrium.

While this definition is satisfactory for the case of a pure substance, so complex a mixture as an ordinary fire brick usually has no single definite melting point according to this definition, since several anisotropic phases may be present, all differing in composition from the isotropic phase produced by fusion. We can then only select the temperature at which the transition from a rigid to a fluid state seems most distinct, and can call this the melting point only by apology. In the case of fire bricks, the transition temperatures so found are fortunately sufficiently definite to make their determination of practical value.

Some substances after being melted and then cooled below the melting point, crystallize so slowly that cooling can be continued down to ordinary temperature without noticeable crystallization, the material usually becoming so viscous that it is for practical purposes a solid, though in consistency with our definition of melting point, it may be considered a liquid. Ordinary glass and silica glass belong in this class.

## REFRACTORY MATERIALS.

### CARBON.

Carbon exists in the allotropic crystalline forms of graphite and diamond, and in the amorphous state. Diamond and amorphous carbon are converted to graphite by the action of very high temperature.

Graphite is the most refractory material known. At the temperature of the carbon arc, about 3800° C., its vapor pressure becomes equal approximately to that of the atmosphere, and it vaporizes without melting. It is very doubtful whether it has ever been melted. At very high temperatures phenomena sometimes take place which give it very much the appearance of having been melted. For instance, if an arc is produced in a space containing no oxygen, the carbon vaporizes from the part heated by the arc, and the vapor condenses on adjoining parts, often forming nodular masses, which look very much as though they had been produced by fusion.

Graphite is a very useful refractory material for laboratory purposes and for many industrial purposes, for the reasons that it is very refractory, conducts electricity, and can be easily machined into almost any shape. Several forms of high temperature laboratory furnaces have graphite electric heaters.

### METALS.

The most refractory metals are of interest in connection with the manufacture of filament electric lamps. Of these metals tungsten is the most refractory and is the one now in use in lamps. Tantalum, molybdenum and osmium are also very refractory. Tungsten is produced in the form of powder by the reduction of its oxide. This powder can be molded into rods, crucibles and other forms, and sintered by heating to 1800° to 2000° C. The material produced in this way is very porous. Compact ductile tungsten, suitable for the drawing of wire for lamp filaments, is made by hammering the porous material, with suitable heat treatment.

Metals of the platinum group are all refractory. Platinum is used for crucibles, thermocouples, resistance thermometers, electric heaters, and other purposes. Electric furnaces with platinum heaters may be used at temperatures up to about 1500° C., though it is commonly not advisable to approach very close to this limit.

Laboratory furnaces with iridium heaters have been used in a few instances, but they are very expensive. They give temperatures up to about 2000° C. The advantage of platinum and iridium heaters over the cheaper graphite heaters is that they can be used in contact with air, while graphite heaters would burn in air and must be used in a vacuum or in a non-oxidizing gas. Graphite produces reduction or contamination in many materials which it may be desired to heat. Some base metals, especially alloys containing chromium and nickel, are used for electric heaters at moderate temperatures. A temperature of 1100° C. is about the limit for such heaters.

### OXIDES.

Many metallic oxides are highly refractory. Magnesia, one of the most refractory, has a melting point of 2800° C., while that of zirconia is possibly higher. Magnesia is used as an industrial and laboratory refractory. Zirconia with yttria was used in the Nernst electric lamp, which has now gone out of use. Within the last few years natural deposits of zirconia have been found in sufficient quantity to form an industrial source. Previously it was obtained from the silicate, zircon.

Lime, with a melting point of 2570° C., is very refractory, and has some advantage in mechanical properties over magnesia. It

has the disadvantage of slaking when exposed to air. It has been used for some laboratory purposes, and also in the lime light, which has now been supplanted by the arc light.

Thoria and ceria are used in Welsbach gas mantles. Beryllia is very refractory, but has received little application.

Alumina, melting at 2050° C., forms the basis of the abrasive known as "alundum," which is made by fusing alumina and grinding the compact mass thus obtained.

Silica is used commercially as brick, and also forms a valuable glass. It melts at 1710° C., forming so viscous a liquid that very little crystallization occurs on cooling, and the product is a glass of very low expansion coefficient, which makes it capable of resisting sudden changes of temperature. Since this is made by fusing quartz, the most common crystalline form of silica, it is often called "quartz glass," though this is not correct, for after fusion it is no longer quartz.

## REFRACTORY BRICK.

The most commonly employed refractory brick is that made of fire clay. The essential ingredient of clay is the compound $Al_2O_3,2SiO_2,2H_2O$. When this occurs in the pure condition it is known as kaolin. When kaolin is heated to a high temperature the resulting material is a mixture of $Al_2O_3,SiO_2$ and $SiO_2$, and has an apparent softening point of 1740° C. This is, therefore, the highest softening point obtainable in brick containing nothing more refractory than clay. Some commercial fire-clay brick approaches within a few degrees of this value.

If the material used contains in addition to clay the mineral bauxite, $Al_2O(OH)_4$, the material produced under the action of heat has an increased proportion of $Al_2O_3,SiO_2$, which has a melting point of 1810° C., and the brick may be more refractory than the best clay.

Silica brick are used in considerable quantity. They are made from a silica rock called "gannister," bonded with a little lime. If made of good material their melting point is very little below that of pure silica (1710° C.).

Magnesia brick of good quality are the most refractory in common use. Good brick is not readily made from pure magnesia, since its bonding qualities are poor. Commercial magnesia brick contains iron oxide, which serves as a binding material.

As the result of the presence of iron and impurities, the melting point is far below that of pure magnesia (2800° C.), but still very high, generally 2000° to 2200° C. When the brick is heated to near its melting point the vaporization of iron and other material causes the melting point to increase and renders its determination rather uncertain.

While lime is too unstable in air to be used as a refractory material on a large scale, the mineral dolomite, which consists of carbonate of lime and magnesia, gives upon firing a mixture of lime and magnesia which is more stable and is of practical use.

Chromite, $FeO,Cr_2O_3$, is used in the manufacture of a brick which has the valuable property of being very resistant to the fluxing action of almost any fused material. It also has a very high melting point, about 2050° C.

While the melting or softening temperature of a refractory brick is perhaps the property most often considered as an indication of its value, many other properties are of importance in various degrees, depending upon the use to be made of it. For some uses, for example in the lower tiers of blast furnaces, it must have high crushing strength, not only cold but also hot. When exposed to contact with furnace tools it must resist abrasive action. In metallurgical furnaces it must usually resist slagging action. Its thermal expansion is often important, since too much expansion may threaten the stability of furnace parts, especially roofs. If it is exposed to rapid changes of temperature or to temperatures that are not uniform, it must resist these without cracking or spalling.

## LABORATORY REFRACTORIES.

In addition to the materials already mentioned, there are a number of others that are adapted to laboratory use or to other use on a small scale.

Asbestos is a familiar material of this class. Its value depends upon its heat insulating qualities and upon the fact that it can be made into sheets, fabric and cord. The kind used most in the United States is a variety of the mineral serpentine. This material has a melting point about as high as that of fire clay, but since it becomes brittle and crumbly at a red heat it is not often used at very high temperatures.

Mica is useful for many purposes because of its transparency,

and the ease with which it can be split into thin tough sheets. When muscovite mica is heated it begins to lose transparency and becomes brittle at about 700° C. These changes increase with temperature until at 1000° it is very friable, while at 1150° it is stronger again, as the result of sintering. It melts at about 1560°.

Porcelain is used for thermocouple tubes and insulators, spark plugs, crucibles, laboratory furnace tubes, and in a variety of ways. The range of melting points is wide; the best is about as refractory as fire clay.

Crucibles, tubes and other forms made from alundum (bonded fused alumina) and bonded silicon carbide are on the market. They are of use when a product less easily cracked than porcelain, or having a higher thermal conductivity, is required. They are usually bonded with plastic clay, and their softening temperature is then practically that of the clay.

The mineral steatite, which is a hydrated magnesium silicate, has some useful properties. In its natural state it is very soft and can be easily cut. If it is then fired it becomes quite hard. It melts at about 1525° C.

## WAR PROBLEMS

The war has given rise to a number of problems relating to refractory materials, of considerable practical importance, both in the production of special military equipment and in the expansion of existing industries. The cutting off of the supply of some materials formerly obtained from Europe, notable magnesite and certain plastic clays, has caused difficulties and made it necessary to give careful attention to the possible sources of such materials in this country.

The war has required the rapid production of large numbers of optical instruments, including field-glasses, range-finders, gun-sights and periscopes. Before the war all optical glass used in the United States was imported from Europe, and this supply having been cut off, the rapid establishment of a new industry presenting considerable technical difficulties was necessary. One of the greatest of these difficulties was the production of the large clay pots in which optical glass is melted. These pots must not only be capable of carrying a great weight of melted glass without danger of cracking, but they must not be readily attacked by the melted glass nor add any coloring matter to it. This problem

has been satisfactorily solved, and the long period formerly required for the drying of such pots has been materially shortened.

The airplane spark plug presents another military problem in refractory materials. The life of a spark plug is none too long in an automobile engine, while in an airplane engine the conditions are much more severe, and the problem of finding suitable refractory insulating material has required serious attention.

Before the war, the best refractory porcelain came from Berlin. Such porcelain is used extensively in pyrometer tubes, which are employed in many important war industries. Its production in the United States has been undertaken, and ware of good quality is now obtainable.

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Salt. (*U. S. Geological Survey Press Bulletin No.* 422.)—Salt is plentiful in the United States, and more of it was produced in 1918 than in any preceding year, yet the rise in its price helped a little to increase the high cost of living. The average price of salt per ton in 1914 was $2.09; the average price in 1918 was $3.72, an increase of 78 per cent. The lowest estimate of human value—the minimum human efficiency—is expressed in the old phrase "He's not worth his salt," but this cheap commodity brought its producers in the United States in 1918 nearly $27,000,000, which was $7,000,000, or 35 per cent., more than they realized in 1917.

Some producers reported that the cost of labor was nearly double that in 1917, and many had trouble in getting laborers of any kind. One producer reported that though the prices were higher in 1918 than in 1917 the profits were less.

The United States exported more than a million and a half dollars' worth of salt in 1918, most of it to Canada and to Cuba, though, strange to note, we sent nearly 23,000,000 pounds, valued at about $193,000, to far-away New Zealand.

Concentration of Sweet Cider by Refrigeration.—*The Weekly News Letter of the U. S. Department of Agriculture* for September 10, 1919 (vol. vii, No. 6, p. 3) describes a process by which sweet cider is concentrated by mechanical refrigeration. The fresh apple juice is frozen, and the frozen mass is crushed, then subjected to centrifugation. The frozen water is thereby separated from the mother liquor which contains the solid matter of the apple juice. Five gallons of juice yield one gallon of a syrupy concentrate. This concentrate has better keeping qualities than ordinary cider, and remains sweet indefinitely if kept in cold storage. By addition of water it may be restored to its original volume, condition, and flavor. J. S. H.

**Delivering Mail to Steamer After It Has Sailed.** (*Scientific American,* vol. cxxi, No. 8, p. 189, August 23, 1919.)—One of the contemplated uses of the airplane in peace-time is that of overtaking steamers at sea for the purpose of placing delayed mail aboard. Obviously, the speed of the average airplane makes it possible to overtake a steamer several hours after it has left the port, thereby extending the mail service time that many hours.

An experiment in delivering mail to a steamer is to be undertaken within a few days by C. J. Zimmerman, a skilled pilot, who will follow the steamer *Adriatic* two or three hours after she has sailed for England, and overtaking her will drop a mail pouch with a wooden float attachment into the sea just ahead of her bow. This experiment will be closely followed by the post-office authorities and the steamship men, in order to determine the practicability of the scheme.

It has also been suggested that steamers might carry small airplanes which, when the steamer neared port, might fly with bags of mail. If airplanes were employed to overtake the steamer, and one or more airplanes employed to make port some hours before the steamer, perhaps eight hours more might be saved in trans-Atlantic mail service. However, such a scheme would call for a considerable number of machines and pilots, and would entail a notable expense.

**The Experimental Kelp-Potash Plant** of the United States Department of Agriculture, was erected during the summer of 1917 and put into operation in the early fall of that year (*Jour. Indus. Eng. Chem.*).

One hundred tons of raw kelp per day are subjected to drying, destructive distillation, lixiviation, evaporation, and fractional crystallization, for the preparation of a high-grade potassium chloride.

By-products, kelp-oils, creosote, pitch, ammonia, bleaching-carbons, salt, and iodine are yielded in commercial quantities by this process. The main problem now in hand is their commercialization. It is believed that they will be made to yield sufficient revenue to enable the main product, potash salts, to be marketed successfully in competition with foreign sources.

Complete operating cost data are being tabulated covering the various details of manufacture. These, together with full specifications and designs, will be made available for the public.

The results obtained to date indicate that it will be possible to establish on kelp, as the basic raw material, a new American chemical industry of importance and usefulness to the nation.

# THE LOW VISIBILITY PHASE OF PROTECTIVE COLORATION.* †

BY

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Since the glare field in the instrument is limited by a circular diaphragm inclined at an angle of 45° to the line of sight, the apparent shape of the field is elliptical, its longer axis being horizontal. The actual area included in the field at any time is represented approximately by the dotted ellipse, *R*, in Fig. 6. Since the piano wire leaders were very small in diameter, they were not visible from the point of observation, being below the limit of visibility set by the resolving power of the eye. The model, therefore, was suspended in the air without any visible means of support, and when the surrounding objects in the same plane were eliminated from the field of view by the diaphragms of the instrument the most important factors upon which the perception of distance depends were rendered inoperative. The model, therefore, when viewed through the visibility-metre had every appearance of a large boat on the horizon.

For the purpose of the experimental determination of the best value of $R_2$ under various weather conditions, a series of nine models was prepared, varying only in reflecting power. The lowest reflecting power was that given by the blackest matt paint obtainable and the highest that obtained by the whitest. The intermediate values were obtained by using gray paints of various reflecting powers. The reflection factors of these models were measured by use of a reflectometer, in which the angle of illumination was 45° and the observation normal to the painted surface. The paints used gave a surface, when dry, that was quite matt, but some specular reflection was present. While the reflection factor mentioned above does not coincide with the value of that term for all possible conditions, it seems to be the closest

* Communicated by Dr. C. E. K. Mees. Communication No. 80 from the Research Laboratory of the Eastman Kodak Company.

† Concluded from page 387, Vol. 188, September, 1919.

approximation to an average value of that term that it is possible to obtain. The values of reflection factor, $R$, for the series of models used are given below:

| Model No. | $R_2$ |
|---|---|
| $F$ 2 | .75 |
| $F$ 12 | .60 |
| $F$ 3 | .45 |
| $F$ 13 | .36 |
| $F$ 4 | .28 |
| $F$ 14 | .20 |
| $F$ 5 | .15 |
| $F$ 15 | .10 |
| $F$ 6 | .05 |

A typical set of observations is given in Table I.

TABLE I.

*Date:* November 23, 1917, 3 to 4 P.M.
*Weather:* Sky covered with heavy uniform clouds, light snow falling, lake rough, strong N. W. wind.
*Station:* 1.

| Model No. | $B_1$ | $B_0$ | $W$ | Log $B_v$ | $B_v$ | $V$ | $\frac{dV}{dR_2}$ |
|---|---|---|---|---|---|---|---|
| $F$ 2 | 335 | 655 | .37 | 3.72 | 5248 | 15.6 | + |
| $F$ 12 | 327 | 630 | .37 | 3.55 | 3311 | 10.1 | + |
| $F$ 3 | 320 | 575 | .40 | 3.16 | 1445 | 4.5 | + |
| $F$ 13 | 320 | 575 | .40 | 2.47 | 1295 | 0.9 | ÷ |
| $F$ 4 | 320 | 575 | .40 | 3.34 | 2180 | 6.8 | — |
| $F$ 14 | 300 | 535 | .40 | 3.45 | 2810 | 9.4 | — |
| $F$ 5 | 287 | 525 | .39 | 3.57 | 3710 | 12.9 | — |
| $F$ 15 | 280 | 550 | .37 | 3.67 | 4670 | 15.7 | — |
| $F$ 6 | 280 | 557 | .36 | 3.74 | 5490 | 19.6 | — |

It will be noted that $W$ is not quite constant but is approximately so for the entire set of observations. Model $F$ 13 gave the lowest visibility value. The reflection factor for $F$ 13 is .36, which is almost exactly equal to $W$, the weather coefficient of which the average value for the set is .38. The visibility values from this set of data are plotted, Curve 1, Fig. 8, as a function of the reflection factors of the various models.

The two elements of the curve intersect at the point $V = 0.9$, $R_2 = .36$. The value of $R_2$ represents the optimum value of the reflection for this particular weather condition and will be designated by the symbol $O_r$.

Another complete set of data is given in Table II. The value of $W$ in this curve is much higher than in the previous case, and not constant for the entire set.

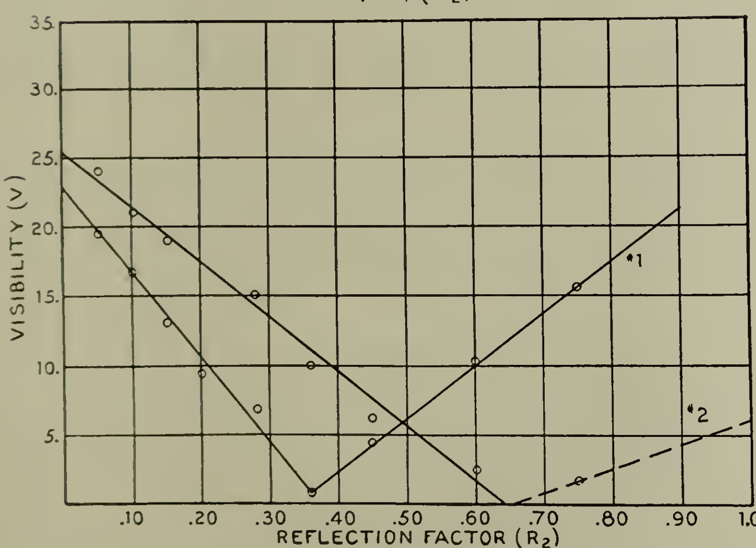
TABLE II.

*Date:* November 22, 1917, 2.30 to 3.30 P.M.
*Weather:* Cloudy, heavy cloud banks, not uniform.
*Station:* 1.

| Model B | $B$ | $B$ | $W$ | Log $B_T$ | $B_T$ | $V$ | $\frac{dV}{dR_2}$ |
|---|---|---|---|---|---|---|---|
| $F$ 2 | 565 | 640 | .63 | 2.98 | 955 | 1.7 | + |
| $F$ 12 | 590 | 730 | .60 | 3.20 | 1590 | 2.7 | — |
| $F$ 3 | 640 | 760 | .61 | 3.60 | 3990 | 6.2 | — |
| $F$ 13 | 710 | 730 | .71 | 3.80 | 6610 | 9.3 | — |
| $F$ 4 | 710 | 680 | .73 | 4.03 | 10800 | 15. | — |
| $F$ 14 | 720 | 670 | .76 | 4.90 | 12400 | 17. | — |
| $F$ 5 | 740 | 630 | .85 | 4.14 | 13900 | 19. | — |
| $F$ 15 | 760 | 630 | .87 | 4.20 | 15900 | 21. | — |
| $F$ 6 | 760 | 630 | .87 | 4.26 | 18200 | 24. | — |

FIG. 8.

$V = f(R_2)$




The variation of visibility with reflection factor.

The data from Table II. are plotted in Fig. 8, Curve 2. In this case it will be noted that for only one visibility value is the

sign of the first derivative $\frac{dV}{dR_2}$ positive, indicating that only one of the models used has a sufficently high reflection factor to give a greater brightness than that of the sky background. Since there is only one point on the element of positive slope, that element is indeterminative in position, but knowing that it should cut the element of negative slope at a point near the axis of $V = O$, its approximate position can be represented by the broken line in the figure. Thus the optimum value $O_r$, of the reflection factor in the case must be approximately .65, which value agrees fairly well with the weather coefficient at the time the readings on models *F* 2, 12 and 3 were made.

The observations on this set of models extended over a considerable period of time, one to four complete sets of observations being made each day. In all, a total of about forty sets were made. It will be impossible to give in detail the data obtained, hence, summarizations will be presented from which the necessary conclusions may be drawn.

It was pointed out in connection with the data presented in Tables I. and II. that the values of $O_r$, the optimum reflection factor, agreed fairly well with the weather coefficient. Theory indicates that this should occur. The data will first be summarized in such a way as to show the experimental verification of this point.

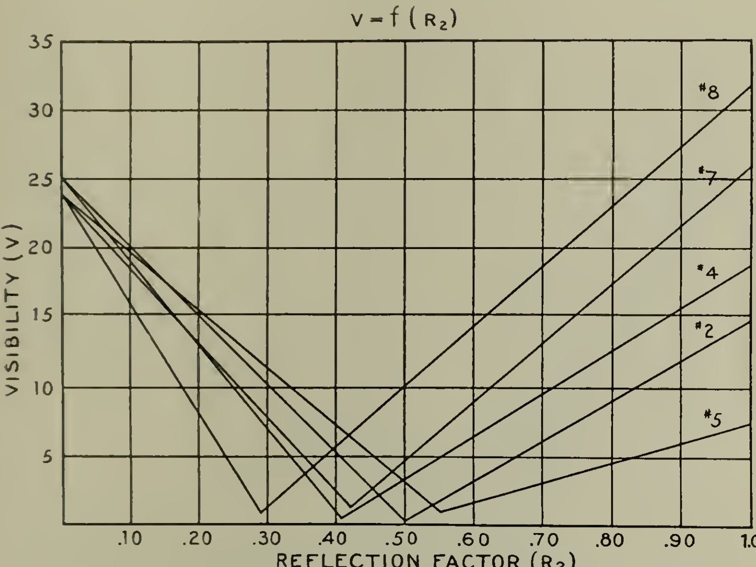
In Table III. are presented the results of ten sets of data on the nine black to white models, *F* 2 to *F* 6. Immediately under each model number is placed the reflection factor value for that model. In column *W* are the values of the weather coefficient for each set and in column $O_r$, the values of the optimum reflection factor as determined by interpolation from the plotted curves.

TABLE III.

| Set No. | *F* 2 | *F* 12 | *F* 3 | *F* 13 | *F* 4 | *F* 14 | *F* 5 | *F* 15 | *F* 6 | *W* | $O_r$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | .75 | .60 | .45 | .36 | .28 | .20 | .15 | .10 | .05 | .... | ... |
| 1 | 15.6+ | 10.1+ | 4.5+ | 1.0+ | 5.8− | 9.4− | 13.− | 17.− | 20.− | .38 | .36 |
| 2 | 7.4+ | 3.0+ | 4.0− | 7.7− | 11.0− | 15.2− | 18.− | 19.− | 22.− | .47 | .50 |
| 3 | 21.8+ | 16.0+ | 10.0+ | 5.0+ | 1.3+ | 6.2− | 10.− | 14.− | 22.− | .30 | .27 |
| 4 | 11.0+ | 5.0+ | 1.0+ | 5.0− | 7.9− | 12.0− | 16.− | 18.− | 23.− | .40 | .41 |
| 5 | 3.7+ | 1.5+ | 5.0− | 7.5− | 12.0− | 15.0− | 17.− | 19.− | 22.− | .59 | .55 |
| 6 | 10.0+ | 6.0+ | 1.7+ | 4.2− | 7.0− | 10.9− | 13.− | 16.− | 22.− | .42 | .41 |
| 7 | 16.1+ | 7.7+ | 1.2+ | 5.0− | 10.0− | 12.0− | 16.− | 20.− | 23.− | .40 | .42 |
| 8 | 22.0+ | 12.5+ | 8.5+ | 3.0+ | 2.5− | 7.0− | 12.− | 15.− | 20.− | .30 | .29 |
| 9 | 12.0− | 6.3− | 12.0− | 14.2− | 18.0− | 19.0− | 21.− | 24.− | 25.− | .77 | .80 |
| 10 | 13.6+ | 10.0+ | 6.4+ | 4.0+ | 1.5+ | 5.5− | 10.− | 15.− | 22.− | .30 | .25 |
| ean | 12.3+ | 7.8+ | 5.4+ | 5.7− | 7.7− | 10.2− | 14.6− | 17.7− | 22.− | .433 | .426 |

In Figs. 9 and 10 are plotted the data from Table III., the number attached to each curve being that of the set of data used in obtaining it. A careful consideration of these curves reveals several interesting facts. It will be noticed that in general the value of $V$ at which the positive and negative elements of a given curve intersect is not zero. This means that there is no value of $R_2$ which results in complete invisibility. This is due to the fact that a color contrast existed between the models and the sky

FIG. 9.




Variation of visibility with reflection factor for tests 2, 4, 5, 7, 8.

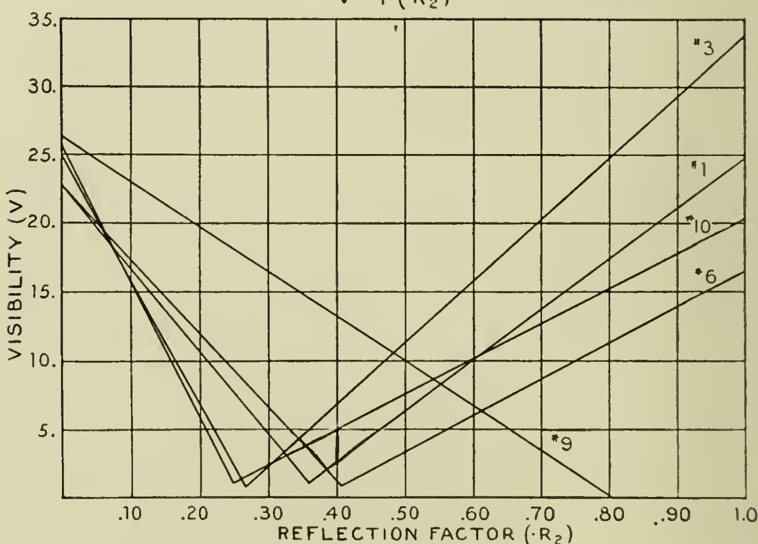
background, resulting in a residual visibility. Therefore, a pure gray cannot be expected to give the minimum visibility.

The curves plotted in these Figs. 9 and 10 are of the same type as the theoretical curves representing $V$ as a function or $R_2$. Now, in computing the values from which theoretical curves representing $V = f(R_2)$ were plotted a value of $k = 1.02$ was taken. This gave for the point from which the elements of negative slope diverge, the point, $Y = 0$, $X = +50$, and $Y = 0$, $X = -50$ as the origin of the elements of positive slope. Now in Figs. 9 and 10 it will be noted that the elements of negative slope converge

to a common point, $Y = 0$, $X = +25$. By using this value in Equation 6 and solving for $k$, a value of $k = 1.04$ is obtained. This indicates the value of $k = 1.02$ was too low for the conditions that exist in the operation of the visibility-meter. In order to compare experimental results with the theoretical requirements, this indicates that a value of $k = 1.04$ should be used in computing the theoretical curves. It will be noted that the agreement between $W$ and $O_r$ is in general quite good and the agreement between the means of the ten sets (Table III.) very good.

FIG. 10.

$v = f(R_2)$

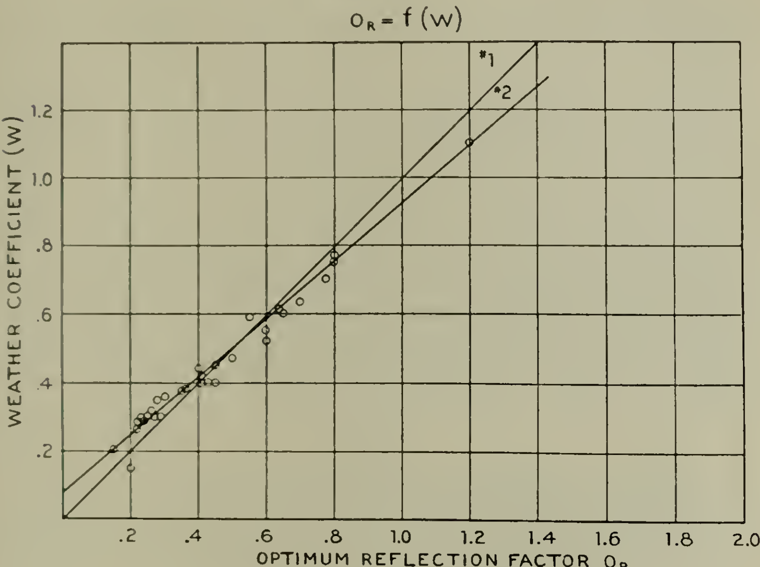



Variation of visibility with reflection factor for tests 1, 3, 6, 9, 10.

Additional data on the agreement between $W$ and $O_r$ are given in Table IV. The values of $O_r$ were obtained in the same way as those in Table III., *i.e.*, by interpolation from curves, $V = f(R_2)$, plotted as illustrated in Figs. 9 and 10. Examination of the data in Tables III. and IV. shows that for low values of $W$, $O_r$ is usually too low, while for high values of $W$, $O_r$ is, in general, too high. The agreement between the two for intermediate values ($W = .40$ to $.60$) is quite good. In order to show this relation in graphic form the curves in Fig. 11 were plotted. Theoretically the curve, $W = f(O_r)$, should be a straight line at 45°

to the axis of reference, Curve 1. The positions of the points plotted from the data in Tables III. and IV. are indicated by the small circles. The most probable position of the experimental curve ($W=f(O_r)$, is the line 2. It will be noted that the experimental curve is of lesser slope than is indicated by theory, but that

FIG. 11.




Theoretical and experimental curves, $Or=f(W)$

it crosses the theoretical curve at the point $W=.51$. This discrepancy between the theoretical and experimental curves has not as yet been accounted for. However, it is relatively small, especially within intermediate values, $W=.35$ to $W=.65$, within

TABLE IV.

| $W$ | $O_r$ | $W$ | $O_r$ | $W$ | $O_r$ |
|---|---|---|---|---|---|
| .20 | .15 | .38 | .35 | .52 | .60 |
| .26 | .22 | .40 | .45 | .55 | .60 |
| .29 | .22 | .40 | .43 | .60 | .65 |
| .29 | .24 | .40 | .45 | .61 | .64 |
| .30 | .23 | .40 | .45 | .63 | .60 |
| .32 | .26 | .44 | .40 | .70 | .78 |
| .36 | .30 | .45 | .45 | .75 | .80* |
| .35 | .28 | .45 | .45 | 1.10 | 1.20* |

which region the great majority of the measured values of $W$ are found to lie. The data derived from Tables III. and IV. are not suitable for deciding upon the mean value of $W$, since these were chosen simply to cover the entire range of the observed values of $W$.

The close agreement between $W$ and $R_2$ called for by theory for a condition of low visibility has now been verified by practical measurements. It remains, therefore, to establish the mean value of $W$ for the weather conditions under which it is desired to obtain a minimum visibility. This can be done for the period over which the observations were taken by carefully weighting and averaging the values of $W$ obtained. The values of $W$, with a verbal statement of the weather conditions, are given in Table V. It will be noted that the weather was in general cloudy. Averaging the values of $W$, exclusive of the seventh value, which is undoubtedly very exceptional, a mean value of .43 is obtained. Therefore, a boat having a reflecting power of .43 would on the average be less visible than any other in a sea area where similar weather prevails. Examinations of the verbal statements of

TABLE V.

| Hour | Weather | $W$ |
|---|---|---|
| 3.00 P.M. | Uniform clouds, medium density, showing | .38 |
| 3.30 P.M. | Cloudy, not uniform, medium density | .45 |
| 10.00 A.M. | Fairly clear, light white clouds over sun | .31 |
| 4.00 P.M. | Cloudy, uniform medium density | .48 |
| 3.00 P.M. | Heavy dark uniform clouds all over | .59 |
| 4.00 P.M. | Sky covered with dark clouds | .46 |
| | Light streak above the horizon | 2.70 |
| 4.30 P.M. | Dense uniform clouds all over | .80 |
| 2.30 P.M. | Clear, light white clouds, local | .30 |
| 10.00 A.M. | Clear sky, light gray fog bank over lake | .36 |
| 2.30 P.M. | Sky perfectly clear, no fog | .30 |
| 10.30 A.M. | Clear light gray fog over lake | .26 |
| 3.30 P.M. | Clear, no clouds | .22 |
| 4.00 P.M. | Cloudy, uniform gray clouds | .45 |
| 9.30 A.M. | Partially clear, foggy | .50 |
| 4.00 P.M. | Light clouds, sun obscured | .48 |
| 9.30 A.M. | Partially cloudy, no sun | .50 |
| 2.00 P.M. | Light veiling clouds over sun | .35 |
| 3.00 P.M. | Light veiling clouds over sun | .45 |
| 4.00 P.M. | Light veiling clouds over sun | .53 |
| Mean | | .43 |

weather show that only five of the twenty observations were taken under clear conditions, the remaining fifteen being for cloudy or partly cloudy weather. That is, 75 per cent. of the observations apply to cloudy or partly cloudy conditions.

Now a careful analysis of weather reports covering the region in which a majority of the sinkings have been occurring shows that 70 per cent. of the days are cloudy. Hence the factor .43 should apply fairly well to the northern portion of the danger zone, and south of it where there is mist. It should be emphasized, however, that in order to establish a more reliable value for $O_r$, it would be necessary to obtain precise and definite data from which to deduce an average value of $W$ for any particular submarine-infested region through which the ship to be painted must travel. This value of $W$ should, of course, apply to the time of year considered. Even on clear days, when the value of $W$ is low during the middle of the day, this value increases during the hours just after sunrise and before sundown, especially if there be some haze or mist in the atmosphere. With the data at present available, however, it seems that the best average value of reflection factor must be between .40 and .45 for the region mentioned.

It will be noted from the curves and data relating to the visibility of the series of models $F$ 2 to $F$ 6 that the visibility never reaches zero for any value of $W$. This is due to the fact that these models were all gray, the saturation being zero and the dominant hue indeterminate; thus color difference always existed between the object and background, giving rise to a residual visibility due to color contrast.

The next step in the work was the determination of the best hue and saturation to give low visibility. The most logical and scientific procedure for the determination of these factors would have been to measure by means of a colorimeter the hue and saturation of the sky. If such measurements could have been made under all conditions of weather and over a considerable period of time, and the results averaged for the desired period and weather conditions, it would have been possible to make up the desired color directly. However, it was thought best and most expedient to obtain the desired information by a method of trial and error. It was evident from the direct visual observations made over a considerable period that the average value of

the dominant hue was situated in the blue-green region and that the saturation was on the average quite low. Several models were therefore made up by painting with various hues of blue-green and of low saturation. They were mounted on the rack in the usual way and observed. One model in the group first prepared was found to be of approximately the correct hue, but the saturation was obviously too high.. A second set of models was then prepared, using the best hue as already determined, but of various saturations. In this way, by a series of consecutive approximations, a hue and saturation were obtained which by observation over a considerable period and under various conditions of the weather was considered satisfactory. The reflection of all models used in this work was kept at the best value of that quantity as previously determined, namely, .40 to .45. The color of the model *F* 20, which was proven to be the best by observation, was then measured on the colorimeter and found to be represented by the specification: Hue (wave length of dominant hue) $= 488\mu\mu$; Saturation (per cent. white) = 88 per cent.

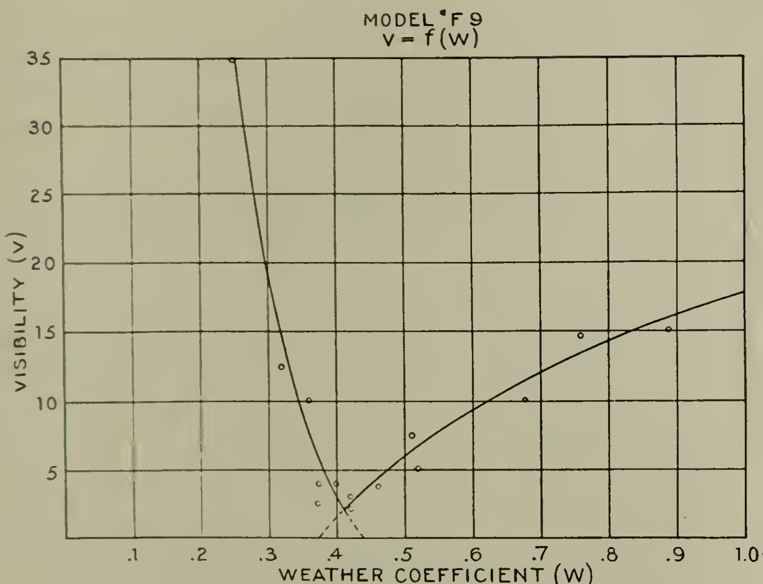
TABLE VI.

| *F* 9 | | *F* 20 | | $R_2 = .43$ | |
|---|---|---|---|---|---|
| *W* | *V* | *W* | *V* | *W* | *V* |
| .37 | 4.0+ | .40 | 1.5+ | .10 | 81.5+ |
| .52 | 5.0− | .47 | 2.5− | .20 | 27.8+ |
| .46 | 3.8− | .70 | 10.0− | .25 | 17.0+ |
| .51 | 7.5− | .90 | 11.5− | .30 | 9.9+ |
| .68 | 10.0− | .30 | 12.5+ | .35 | 4.6+ |
| .48 | 1.0− | .34 | 5.0+ | .40 | 0.9+ |
| .87 | 15.0− | .25 | 2.5+ | .414 | 0.0 |
| .76 | 14.0− | .42 | 2.5+ | +.0 | 0.0 |
| .30 | 20.0+ | .38 | 4.0+ | .447 | 0.0 |
| .36 | 10.0+ | .55 | 5.5− | .50 | 2.6− |
| .40 | 4.0+ | .42 | 0.9+ | .60 | 6.3− |
| .25 | 35.0+ | .45 | 1.0− | .70 | 9.0− |
| .40 | 1.0+ | .78 | 9.0− | .80 | 11.0− |
| .42 | 3.0− | .35 | 8.5+ | .90 | 12.6− |
| .32 | 12.5+ | .50 | 3.0− | 1.00 | 13.8− |

The data on Model *F* 9 are given in Table VI., column *F* 9, these being the visibility values determined under various weather conditions. In this case the model is constant, while *W* varies. Hence, the data plotted as a curve must be the form of $V=f(W)$, as shown in Fig. 12. The minimum visibility is 2.2 at $R_2=.41$. The

residual visibility in this case was due to saturation contrast. The data on model $F$ 20 are given in column $F$ 20, Table VI. and the curve plotted from them in Fig. 13, Curve 1. It will be noted that in this case the minimum visibility is very low (0.3) and that this occurs at $R_2 = .43$. In order to determine how nearly the experimental curve, $V = f(W)$, for this model agrees with the theoretical, the curve shown as a dotted line and numbered 2 in Fig. 12 was plotted. The fact that the minimum visibility of model $F$ 20

FIG. 12.

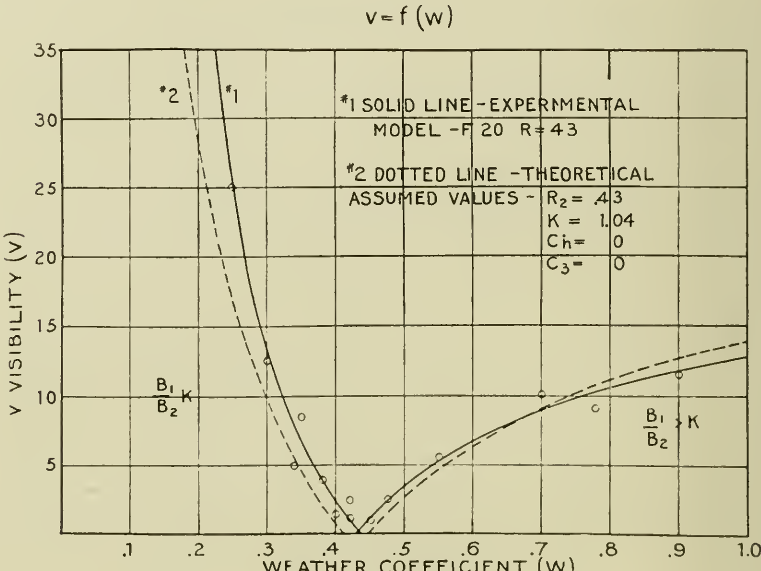



Visibility test of Model F9.

as shown by Curve 1, Fig. 13, was practically zero shows that the hue contrast, $C_h$, and the saturation contrast, $C_s$, between model and background must have been very small. Hence, the curve, $V = f(W)$, for the model should agree quite closely with the theoretical curve, $V = f(W)$, for brightness contrast alone. Taking from previous experimental results that $R_2 = .43$ (the reflection factor of $F$ 20), solution of Equation 12 for various values of $W$ gives the data, Table VI., column $R_2 = .43$, from which Curve 2 was plotted. It will be noted that the two curves agree quite well for the region when $W = .45$ to $.90$, but that some

difference occurs for lower values of *W*. This is probably due to the presence of a color contrast which existed only under those conditions of weather resulting in low values of *W*. It is very evident that there will be weather conditions for which the color of this model, *F* 20, will not be correct either in hue or saturation, but from the data available it seems quite certain that this specified color will be best, from the standpoint of low visibility, for any locality where a large proportion of the days are cloudy or partially cloudy.

FIG. 13.




Visibility test of Model F20.

It should be borne in mind that the visibility specifications expressed above are based on the following hypotheses:

(1) Background composed entirely of sky immediately adjacent to horizon line.

(2) Predominating weather condition entirely or partially cloudy, $W = .40$ to $.45$.

(3) Visible surfaces of object uniformly illuminated by natural light, that is, sunlight more or less diffused by clouds.

(4) If the surfaces are such that the value of $R$ depends upon the conditions of illumination and the direction of observa-

tion, the value of $R$ referred to in the specifications above is that particular value obtained by measurement under the existing conditions of illumination and from the direction of the specified point of observation.

The first hypothesis represents the condition existing in practically every case of the observation of a surface craft from a submarine. The second conforms with the conditions in a large and most hazardous part of the present submarine danger-zone. This conclusion is based upon a careful summary of all the available data relating to the weather of these regions. The third assumption does not hold at all for an object of such structural peculiarities as a ship. The portion of the sky forming the background in most cases is of such small, solid angular dimensions that it is usually uniform in brightness, hue and saturation. Hence, for low visibility the boat should also be uniform in brightness and color as observed from the specified point. For every visible surface element, therefore, the value of $B$ must be the same. Now, $B = E \cdot R$, hence, if $E$ varies from point to point, $R$ must vary also, and inversely, in order to keep $B$ constant. It will be necessary, then, to so vary the reflecting power of the paint applied to the areas where the illumination is too high or too low, so that the brightness of all visible surfaces shall be as nearly uniform as possible when viewed from the specified point of observation. A good approximation to the fourth assumption is obtained by the use of a matt paint. However, since no paint gives absolutely matt surface, it may be necessary to reduce the reflecting power of these surfaces that are so inclined to the line of sight as to give specular reflection in the direction of that line. The treatment of a given structure required to obtain the desired result necessitates the careful study of the individual structure and of the position, shape and relative intensity of the high lights and shadows under the lighting conditions for which it is desired to obtain low visibility. This treatment should be such that the projected effect, that is, the apparent brightness, hue and saturation, as measured from the specified point of observation, shall be equivalent to that of a perpendicular surface (exposed to the full illumination of the natural existing conditions) uniform in reflection factor, hue and saturation.

In order to determine the relative merits of the camouflage schemes proposed by various individuals and firms for the pro-

tection of surface craft from attacks by submarines, a large number of visibility measurements were made. The models used were of the standard profile type, and were prepared by the various parties advocating the use of these systems of protective coloration.

The principles upon which these various systems are based vary greatly from group to group, but for the purposes of this discussion they will be divided into two general classes: (1) those in which the size of the individual unit employed in carrying out the color scheme is below the resolving power of the eye when at a distance of 6000 yards, (2) those in which the size of unit is above the resolving power of the eye at a distance of 6000 yards. In case of the first class, no matter what the shape or color of the units used, the model as observed from Station 1 appeared of a uniform brightness, color and saturation when the pattern used was regular. In case the pattern was irregular, certain variation in general tone could be detected, but no units were visible as such. This system of coloration is based upon the assumption that a surface so painted will be less visible than a surface painted with a solid color of the same reflecting power, hue and saturation as results from the blending, due to loss of resolution, of the units in a broken color system. From the physical standpoint there seems to be no support for such an assumption; but it was considered advisable to make a large number of measurements in order to prove or disprove its validity. This system is sometimes referred to as "vibration," or "scintillation" system, although the exact sense of these words used in this connection is not entirely clear. The models designated by the letters *A*, *D*, *E* and *H* fall into this classification, although it should be remembered that such classification is not at all rigid.

A large number of readings were made on the models of these various groups, but it does not seem desirable to present all of these data at this time. However, in order to compare directly the merits of these different systems of coloration, a summary of data is made in Table VII. The data are tabulated in columns designated as follows:

Model No. = The identification number.
$W_m$ = The value of weather coefficient for which visibility is minimum.
$V_m$ = Minimum visibility.
$V_{.43}$ = Visibility of the model when $W = .43$.

$V_x$ = Average visibility for the range $W = W_m + .10$ to $W = W_m - .10$.

Color = Verbal indication of whether the model was painted with a solid or broken color scheme.

Unit = Designation of the size of unit employed in case a broken color system was used. "Small" indicates that the units were below the resolving power of the eye when the model was at a distance equivalent to 6000 yards. "Large" indicates that the units were above the resolving power of the eye at that distance. In the case of Model G1 the units were large, but due to the very low contrast between units they were not visible at the specified distance. Hence this model to all intents and purposes should be regarded as belonging either to the solid color class or to the small unit. broken color group.

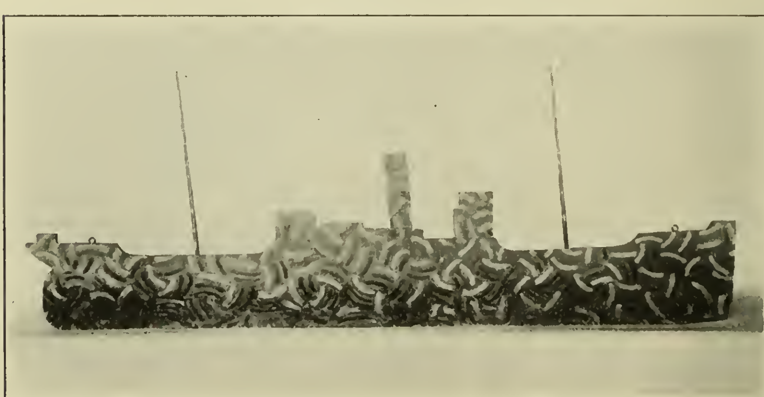
TABLE VII.

| Model No. | $W_m$ | $V_m$ | $V_{43}$ | $V_x$ | Color | Units |
|---|---|---|---|---|---|---|
| *F* 12 | .51 | 1.2± | 5.6± | 3.0 | Solid | |
| *F* 3 | .42 | 1.4± | 2.6− | 4.3 | Solid | |
| *F* 13 | .35 | 1.6± | 5.5− | 7.0 | Solid | |
| *F* 4 | .31 | 1.3± | 9.0− | 10.5 | Solid | |
| *F* 9 | .41 | 2.2± | 3.0− | 6.1 | Solid | |
| *F* 20 | .43 | 0.3± | 0.3± | 3.2 | Solid | |
| *R* 43 | .43 | 0.0± | 0.0 | 2.0 | Solid | |
| *A* 5 | .38 | 1.5± | 4.7− | 5.3 | Broken | Small |
| *B* 3 | .31 | 3.0± | 7.0− | 7.8 | Broken | Large |
| *C* 1 | .32 | 3.0± | 7.5− | 8.6 | Solid | |
| *D* 1 | .49 | 2.0± | 7.2+ | 5.2 | Broken | Small |
| *E* 1 | .49 | 4.2± | 7.5+ | 6.6 | Broken | Small |
| *G* 1 | .30 | 1.0± | 10.0− | 7.8 | Broken | Large |
| *H* 1 | .30 | 3.0± | 9 5− | 10.5 | Broken | Small |

Now, in discussing the data given in Table VII., it is desired to emphasize the significance of the term $V_x$. It was suggested in support of the small unit system of broken color that although such a method of painting might not produce a lower minimum value of visibility, possibly the average visibility for a fairly large variation in the weather coefficient might be less than in case of a solid color. This possibility is based upon the assumption that the mean reflecting power, hue and saturation of a surface covered with a series of small colored patches will, when subject to a given variation in the intensity and quality of the incident light, change according to laws other than those governing the change in reflection factor, hue and saturation of a solid color when subject to the same variation in the illumination. In order to test the validity of such an assumption, the value of $V_x$ was computed

for the various models. Since the position of minimum visibility is not the same for all models, no fixed range of $W$ values could be used for a comparison upon this point. It was necessary, therefore, to consider a given range of $W$ values above and below $W_m$ for each individual model. The data obtained indicate that the broken color systems show no advantage over the solid colors. A considerable variation in the $V_x$ values does occur, but it will be noted that this is a function of $W_m$ and not of the solid or broken characteristics of the color scheme. A consideration of the theoretical curves shows that $V_x$ should vary according to some inverse function of $R_2$.

FIG. 14.

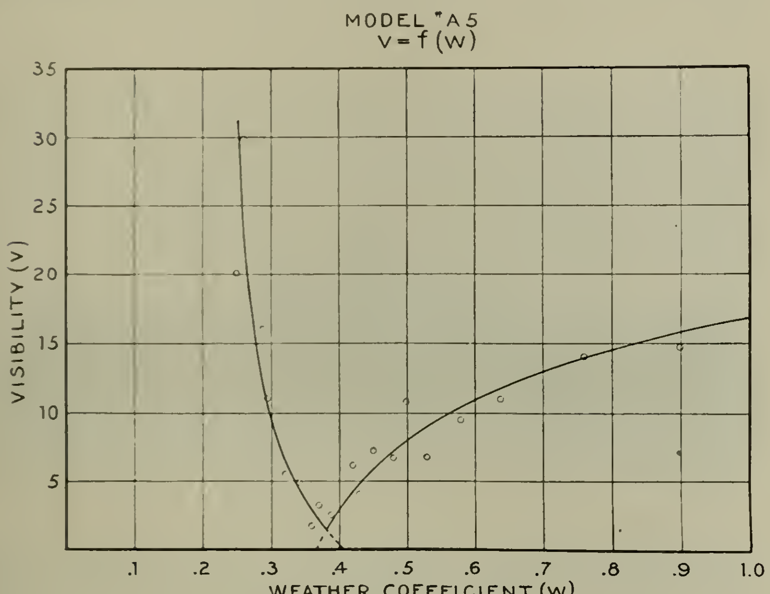


Photographs of a Herzog Model.

In order to test the relative merits of the broken and solid color systems, models of exactly the same mean reflecting power, hue and saturation, should be compared. No models precisely filling these requirements were found among those used, numbers $F$ 20 and $A$ 5 being those that most nearly approach these conditions. It will be noted that $F$ 20, solid color, shows a lower average visibility than $A$ 5. The difference between the two values is not great and is due partially to the fact that $W_m$ is higher for $F$ 20, and partially to the lower color contrast between model and background in case of $F$ 20. The conclusions to be drawn are, therefore, that visibility is a function of mean reflecting power, hue and saturation, and that nothing is either gained or lost by the use of a system of broken colors.

While it is not considered necessary to give in detail all of the data on which the above conclusions were based it may be of interest to present some of this data, together with the curves plotted therefrom, and photographs of the models upon which the observations were made. This will serve to give the reader some idea of the type of models examined and the shape of the curves obtained by plotting visibility as a function of "weather coefficient." In Table VII. are given the data on models *A* 5, *D* 1, *E* 1, and *H* 1.

FIG. 15.



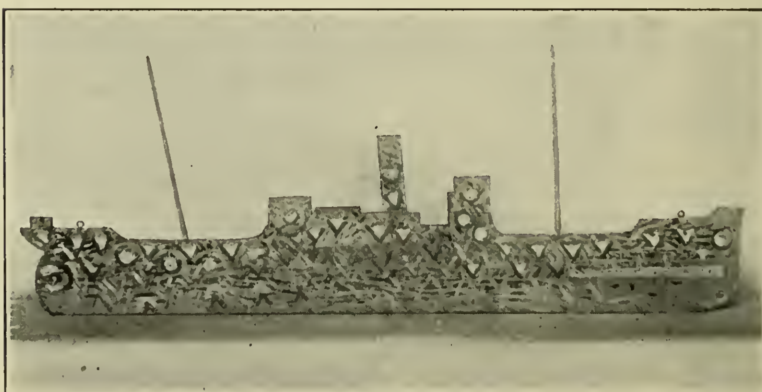

Visibility test of a Herzog Model.

The data on the model *A* 5 (Herzog system) shown in Fig. 14, are given in column *A* 5, Table VII., and the curve, $V = f(W)$, is plotted in Fig. 15. It will be noted that the minimum value of visibility occurs at the point, $V = 1.5$, $W = .38$. The mean effective reflection factor is, therefore, equal to .38, which is too low for the average value of $W$ (.43) previously determined. The curve is of the same general type as those obtained from the models of solid color (the *F* group), and shows no superiority in any respect. The hue and saturation of this group of models compared quite satisfactorily with the last model of the *F* group,

$F$ 20. The dominant hue was, in general, too far toward the red end of the spectrum, although this was not true for all models of the group.

Model $D$ 1 (Pleuthner) is shown in Fig. 16. The pattern was rather irregular and blended completely at 6000 yards into a uniform brightness, hue and saturation. The resultant hue was yellow and of fairly high saturation. The reflection factor was also high. The data are given in Column $D$ 1, Table VII., and the resulting $V = f(W)$ curve in Fig. 17. The minimum visibility occurs at the point $V = 2.0$, $W = .49$. It is evident that the mean

FIG. 16.

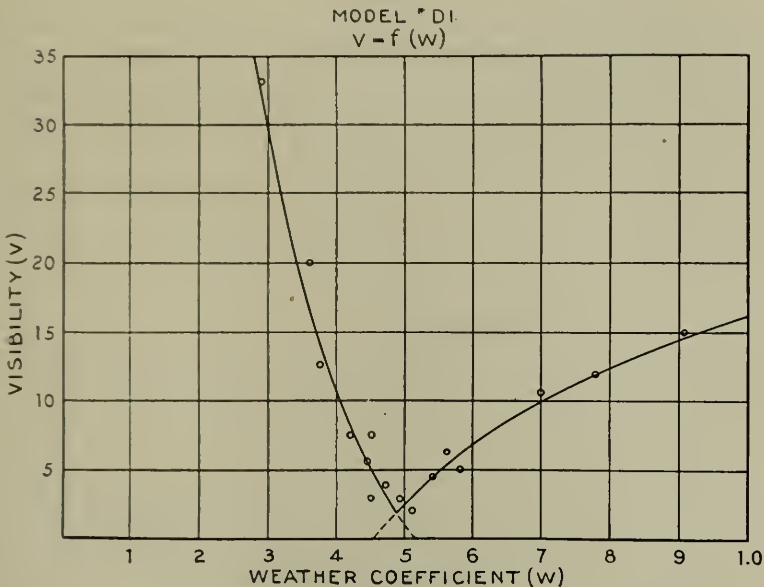


Photograph of the Pleuthner Model.

effective reflecting power was too high. The wave length of the dominant hue was too low and the saturation too high. The high value of minimum visibility is due to a combination of hue and saturation contrast.

Model $E$ 1 (Gomez) is shown in Fig. 18. This model was painted with horizontal stripings, blending gradually one into the other, the average reflecting power increasing from the water line upward. The intention evidently was to imitate the horizontal stratification of clouds sometimes observed just above the horizon. The angular dimensions of these stripes were entirely too small at a distance of 6000 yards to simulate any natural stratification ever observed by the writer. In fact, at the distance mentioned, the striping was not visible at all, the blended effect being of a

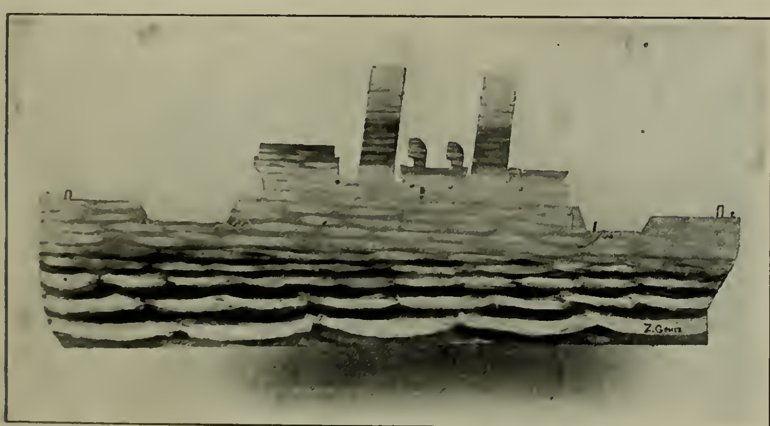
FIG. 17.




Visibility test of the Pleuthner Model.

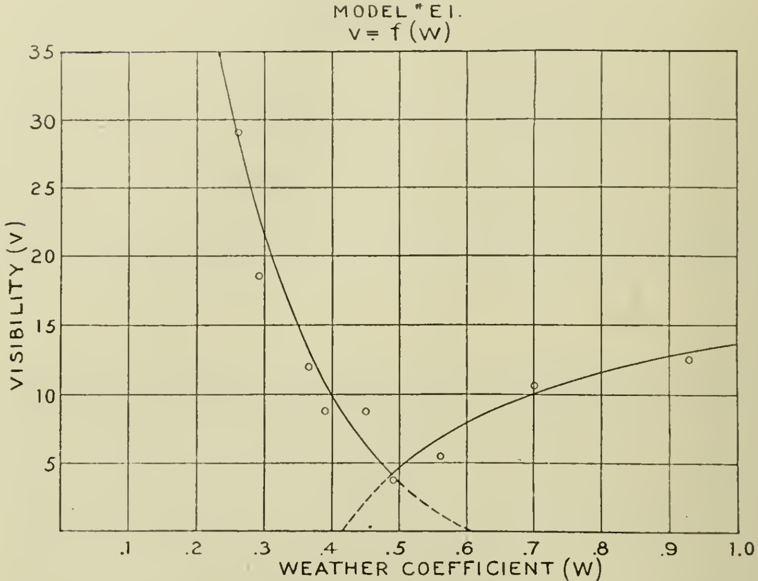
gradual diminution in brightness upward from the water line. The data are given in Column $E$ 1, Table VII., and the curve, $V = f(W)$, in Fig. 19. The minimum value of visibility occurs at

FIG. 18.



Photograph of the Gomez Model.

FIG. 19.

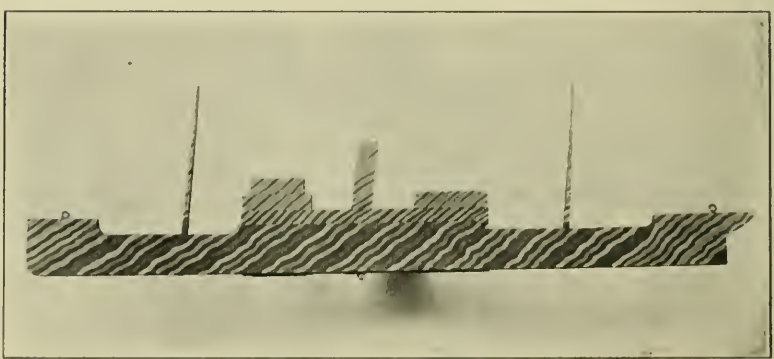



Visibility test of the Gomez Model.

$V = 4.5$, $W = .49$. The mean effective reflection factor was too high, the saturation satisfactory and the wave length of the dominant hue too low, the mean hue being yellowish.

Model *H* 1 (Patterson-Sargent Company), shown in Fig. 20, was painted with wavy diagonal stripes inclined at an angle of

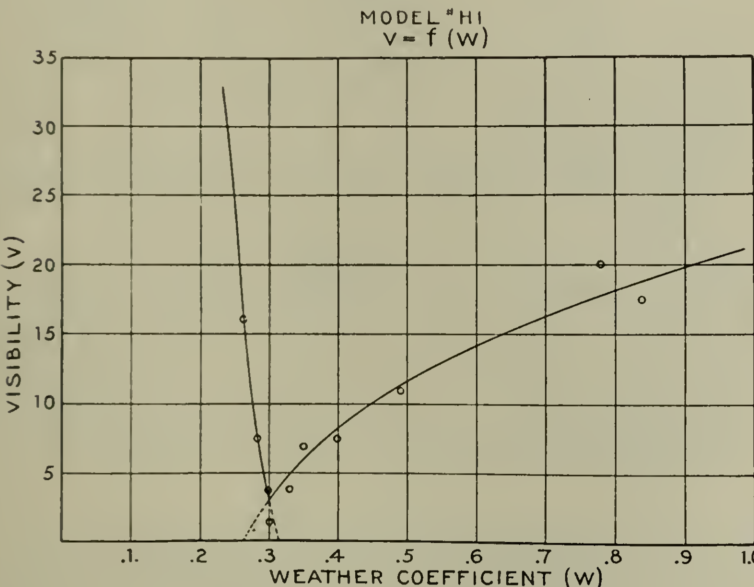
FIG. 20.



Photographs of the Patterson-Sargent Company Model.

45° to the water line. The colors used were of high saturation and low reflecting power. These stripes were not visible at 6000 yards, equivalent viewing distance. The data are given in Column $H$ 1, Table VII., and the curve is shown in Fig. 21. Minimum visibility occurs at $V = 3.2$, $W = .30$. It is evident, therefore, that the mean effective reflection factor is much too low. The hue was rather indeterminate and the saturation very low. The few curves that have been shown will serve to illustrate the

FIG. 21.




Visibility test of the Patterson-Sargent Company Model.

type of data obtained, the method of interpretation and the conclusions drawn from an examination of the visibility-weather coefficient relation.

The United States Navy Department placed at the disposal of the Submarine Defense Association the U. S. S. *Gem* for its investigations. The vessel was painted Omega gray on one side, the color which our experiments indicated was the best for low visibility in the northern portion of the danger zone. To confirm these conclusions, several observations of the U. S. S. *Gem* for

visibility were taken at sea off New London. The following are two records:

(1) Observation Station on the deck of a submarine. (Long Island Sound off New London.)

*Time:* 10.30 A.M.
*Date:* March 10, 1918.
*Weather:* Very foggy.

| Direction | Side | B (Sky Brightness) | Visibility | Distance |
|---|---|---|---|---|
| *N* | Starboard | 1450 m. l. | 2.8 | 500 yds. |
| *S* | Starboard | 1450 m. l. | .1 | 800 yds. |
| *N* | Port | 1450 m. l. | 1.8 | 500 yds. |
| *S* | Port | 1450 m. l. | .1 | 800 yds. |

(2) Observation Station on the south side of Fisher's Island.

*Time:* 2.15 to 3.20 P.M.
*Date:* March 5, 1918.
*Weather:* Brilliant white haze lying close to surface of water. Sun overcast with thin white clouds. Sun visible and casting fairly strong shadows.

| | | B (Sky Brightness) | Visibility | Distance |
|---|---|---|---|---|
| Observation at 2.15 P.M. to | S. W. | 6280 m. l. | 1.5 | 1500 yds. |
| | S. | 4750 m. l. | .45 | 1500 yds. |
| | S. E. | 3600 m. l. | .2 | 1500 yds. |
| Less fog over the water: | | | | |
| Observation at 2.53 P.M. to | S. | 3750 m. l. | 2.5 | 1500 yds. |
| Observation at 3.20 P.M. to | S. W. | 4120 m. l. | 4.3 | 1500 yds. |

Beyond about 3000 yards the vessel could not be located even with binoculars.

### CONCLUSIONS ON LOW VISIBILITY COLORATION.

In summarizing this study, the following points should be emphasized. The experimental observations show that:

(*a*) Broken color systems employing contrasting units so large as to be visible as units at the distance considered are objectionable. The contrast between juxtaposed units or between some of the units and the sky background tends to increase visibility.

(*b*) Broken color systems employing units so small as to be invisible as such at the distances considered are neither advantageous or detrimental. The visibility in such cases depends entirely upon the mean effective reflection factor, hue and saturation of the surface, resulting from the reflection factor, hue

and saturation of the surface, resulting from the blending of the units of the design into an apparent uniformity at the distances considered.

(*c*) A solid color system produces low visibility when

$$R_2 = W,$$
and
$$S_2 = S_1,$$
$$H_2 = H_1.$$

(*d*) The average visibility, $V_x$, for a given variation in $W$, varies according to some inverse function of $R_2$; the greater the value of $R$, the less the magnitude of $V_x$.

(*e*) For a weather condition which is considered to be representative of the average condition in the northern portion of danger zone, where the weather is 70 per cent. cloudy or there is mist, the lowest visibility is given by a surface having the following specifications:

| | Hue | Saturation | Reflection Factor |
|---|---|---|---|
| Omega ($\omega$) Gray.... | 488 $\mu\mu$ .... | 88 per cent. .... | $W = .43$ |

(*f*) For a weather condition which is considered to be representative of the average condition in the southern portion of the danger zone when the weather is 40 per cent. to 50 per cent. cloudy and there is no mist, the lowest visibility is given a paint by the following specifications:

| | Hue | Saturation | Reflection Factor |
|---|---|---|---|
| Psi ($\psi$) Gray.... | 478 $\mu\mu$ .... | 88 per cent. .... | $W = .35$ |

## DECEPTIVE COLORATION.

Considering now the second subdivision of protective coloration as a means of defense against submarines, it is evident that a problem of quite different type confronts the investigator. This problem appears to be less amenable to exact scientific treatment than that of low visibility, at least being less physical and more psychological in nature. It is quite evident that, if any deceptive effect is to be produced the elements of the design employed must present relatively great contrasts either in brightness or color and must be of sufficient size as to be visible at the distances at which it is desired the deception shall become operative. If such contrast exists, some of the elements of the pattern must present a marked contrast with the sky background as well as with the contiguous units of the design. This being the case, such elements must be

distinctly visible as such, thus betraying the presence of some object not naturally a part of the sea or sky. No matter how grotesque the shape or color of such elements, it seems almost certain that any intelligent submarine commander observing them and knowing that ships are being protectively colored would interpret them as indicating the presence of a ship of some kind. It is, therefore, certain that such coloration is directly antagonistic to the production of low visibility, thus decreasing the probabilities of a ship escaping detection and increasing the chances of an attack being made.

It does not appear that anything is to be gained by painting a ship to look like any object other than a ship or so as to make it appear merely as a grotesque shape. Any plan of deceptive coloration to be effective must operate in such a way as to produce some definite effect such as to confuse or mislead the submarine commander in the measurements or estimates upon which his subsequent actions in making the attack are based. Thus, any deception regarding the speed, course or range of the craft to be attacked resulting from the scheme of deceptive coloration employed will tend to increase the probabilities of the failure of the attack.

A large number of optical illusions have been collected from the psychological literature and examined from the standpoint of applicability to the production of deception under the conditions existing in this problem. Having considered the methods of observation used by the submarine commander and the nature of the apparatus at his disposal for obtaining these observations, it seems that the only type of illusions offering any possibility of advantageous use in connection with this problem are those based upon the principle that a deception regarding the course of the vessel so painted might be produced.

Since deceptive coloration requires the visibility of pattern to accomplish its object, and low visibility coloration requires uniformity in order to match the sky background, it is evident that in general the two methods are directly antagonistic. In spite of this, it is possible to reconcile the two systems and to devise a system of protective coloration based upon the principle of both "low visibility" and "deceptive" coloration. This possibility is due to the fact that the eye fails to resolve the images of objects when such objects subtend very small visual angles. It is due to

this fact that a surface covered with a pattern made up of units contrasting either in brightness or color or both appears as a surface uniform in brightness and color when viewed at a sufficiently great distance. The resolving power of the eye or of any optical instrument depends upon the aperture ratio of the system. Assuming a pupillary diameter of 4.0 mm., the resolving power of the eye expressed in terms of visual angle is approximately 30″ of arc. This, in terms of linear dimensions, corresponds to a distance of .15 mm. at one metre or 10 inches (24 cm.) at one mile ("Outlines of Applied Optics," P. G. Nutting, p. 65). These values apply to conditions of very great contrast between object and background and in case contrast is low the visual angle for resolution is probably somewhat larger.

By taking advantage of this failure of the eye to clearly resolve objects of small visual angle, a design may be constructed consisting of contrasting elements which will be invisble at any desired distance. The distance at which these elements of design are just below the resolving power of the eye may be termed the "blending" distance. A surface on which such a design exists will, at distances greater than the blending distance, appear to be uniform in brightness and color, while at distances less than that the pattern will be clearly visible. Now, by properly adjusting the brightness, color and relative sizes of the units of any such design, the surface may be made to appear, when viewed from beyond the blending distance, as a uniformly colored surface of the proper brightness and color to give minimum visibility, while at closer range the elements of the design will be visible and may be so arranged as to produce a deceptive effect.

Two colors have been worked out which, when applied to equal areas of any surface, will, when viewed at distances greater than the blending distance of the pattern, result in the low visibility color, that is, the Omega ( $\omega$ ) gray. The two components of this pair of colors are given by the following specifications:

| Name | Hue | Saturation | Reflection Factor |
|---|---|---|---|
| (1) Blue | $474\mu\mu$ | 95 per cent. white | .59 |
| (2) White | $554\mu\mu$ | 78 per cent. white | .26 |

It should be emphasized that these two colors must be applied to equal areas of the surface considered if it is to produce the $\omega$ gray beyond the blending distance, at which the transition from the deceptive design to low visibility color occurs.

In order to produce the Psi ( $\psi$ ) gray, which gives low visibility in regions where the average value of $W$ is .35, another pair of colors was established, being specified as follows:

| | Name | Hue | Saturation | Reflection Factor |
|---|---|---|---|---|
| (1) | Blue | $476\mu\mu$ | 51 per cent. white | .11 |
| (2) | White | $484\mu\mu$ | 95 per cent. white | .56 |

These colors also must be applied to equal areas of the surface considered if it is desired to produce the $\psi$ gray at or beyond the blending distance. The size of the units of the design must be adjusted to the proper size in order to obtain the desired value of blending distance. It is the writer's opinion that the most effective type of protective coloration will eventually be found to embody some such combination of the two general types.

In closing this paper no attempt to present a complete summary will be made, although it may be well to recall a few of the most important points. The subject of protective coloration quite naturally divides itself into two main divisions: "low visibility" coloration and "deceptive" coloration. These in general are antagonistic in principle.

The subject of low visibility has been quite thoroughly treated both from the theoretical and practical points of view. An instrument for the measurement and numerical specification of the visibility of an object under any condition of lighting has been devised and constructed. A large number of measurements of the visibility of profile models under conditions of natural lighting have been made. As a result of this work, two colors designed to give minimum visibility in different parts of the danger zone have been developed and specified. For that part of the zone where 70 per cent. of the days are cloudy or partially so, the color designated as $\omega$ (Omega) gray will give minimum average visibility, while for that region where 40 per cent. of the days are cloudy or partially so the color designated as $\psi$ (Psi) gray will give the best results. In order to obtain the lowest possible visibility the boat should be so painted that from the desired point of observation the projected effect is equivalent to flat surface conforming to the above specifications. This necessitates certain modifications of structural details as well as the modification in the constitution of the paint applied to various parts of the structure in order to eliminate regions of shadow and high light.

The possibility of combining the two general systems, of protective coloration, low visibility and deceptive coloration, is pointed out and two pairs of colors suitable for such use are specified. In general, it is concluded that the probability of a filter being found to obviate the effect of the protective scheme is much greater in case of deceptive patterns composed of units exhibiting high saturation and hue contrast than in the case of low visibility coloration or of deceptive designs employing units of low saturation contrast.

In closing, the author wishes to acknowledge his indebtedness to Mr. Lindon W. Bates of the Submarine Defense Association (under whose auspices this work was carried out) for his coöperation and encouragement given so freely throughout the course of the work, and also to Dr. C. E. K. Mees, Director of the Research Laboratory of the Eastman Kodak Company, for his many helpful suggestions, and to Mr. Prentice Reeves, also of this Laboratory, for his able assistance in carrying out the experimental part of the work.

ROCHESTER, N. Y.
May 1, 1919.

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**The Magnesite Industry in the United States.**—Magnesite (Magnesium Carbonate) is largely employed in the steel industries, and the United States is the largest consumer, taking about 50 per cent. of the world's output. Before the war fully 90 per cent. of this was imported, the bulk coming from Austria-Hungary, and the balance from the Grecian quarries. With the outbreak of the war the Austrian supplies were at once cut off, and after 1916 those from Greece were seriously curtailed. In 1917, the domestic consumption was over 355,000 tons valued at more than $3,700,000, and nearly 90 per cent. of this was obtained within the United States. A great new industry was developed in the State of Washington, while the California industry was very much expanded. A magnesite industry sprang up in Quebec, and although the product was inferior in quality to that produced in the United States, yet the nearness to the great eastern manufacturers made this source competitive. The chief handicap to the western magnesite industries is the long railroad haul, competing with cheaper ocean carriage. The American magnesite is purer than the Austrian, the latter having a notable iron content, but this impurity is somewhat of an advantage in the steel industries. This objection, however, has been satisfactorily overcome by adding a small amount of an iron compound to the American product.

The restoration of shipping conditions will bring about a formidable competition with the American products, and while some of the magnesite from Venezuela may compete with the European output, yet the latter, especially the Austrian, will dominate the market if anything like pre-war prices prevail. Under these conditions the western output would be limited to the market west of the Mississippi. The precise line of contact will depend on several conditions, but the concentration of the steel industries regions east of the Mississippi will give great advantage to the foreign producer.

The question, therefore, becomes of considerable difficulty when the tariff problem is brought in, and data upon the subject have been collected by the United States Tariff Commission, and printed as a bulletin of information, from which publication the above data are taken. H. L.

**Mineral Production of the United States in 1918.** (*U. S. Geological Survey Press Bulletin No.* 422.)—The total value of the minerals produced was about $5,526,000,000, more than half a billion dollars in excess of the value recorded for 1917, but the total quantity produced was less. The output of fuels was greater than in 1917, though somewhat less anthracite coal was marketed. The increase in the quantity of coal marketed was about 5 per cent., but the increase in value, due to higher prices, was more than 17 per cent. It is significant that though the increase in the quantity of petroleum marketed was only a little more than 4 per cent. the increase in value was over 32 per cent.

The value of the metals produced was about 3 per cent. greater in 1918 than in 1917. The figures show that less iron ore and steel were produced, but here again values were higher. A little more pig iron was made, though the quantity shipped was less. Copper and zinc not only in themselves but as the components of brass are perhaps next in importance to iron in the world's industry to-day, and in 1918 they stood high on the list of war metals. A little more copper but less zinc was produced, and the values of both were lower, that of zinc falling about 25 per cent. The output of the war metals manganese and chromite, used in hardening steel, was greater than in any preceding year. Chromite increased 88 per cent. in quantity and 275 per cent. in value over 1917, and the increases in manganese ore were 136 and 100 per cent., respectively. Less gold and silver were mined than for many years. Though the price of silver rose from 81 cents an ounce in 1917 to nearly 97 cents in 1918, the increase was not enough to cover the increased cost of mining.

The output of building material—clay products, building stone, cement, lime, gypsum—showed a great decline.

The domestic production of potash in 1918 was 54,000 tons, an increase of 68 per cent. over the output in 1917.

# AIR SPEED INDICATORS FOR DIRIGIBLES.

BY

THE AERONAUTICS STAFF, U. S. N.*

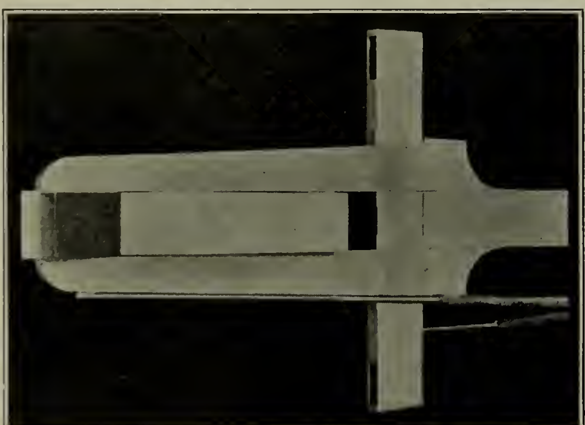
Construction Department, Washington Navy Yard.

To meet the war-time needs of the Navy for an air speed indicator for dirigibles, a speed nozzle was developed having the following required characteristics: water-proofness, accuracy in veering winds, and pressure intensity to admit of a rugged aneroid gauge. The development took two forms, both based on the well-known double-throat venturi, but made waterproof by shielding the smaller inner venturi from the direct impact of drops or spray. The first, being too heavy, was abandoned after field trial, in favor of the second which was lighter and easier to make.

## PART I.

Figures 1 and 2 show the construction of the first instrument. In principle it consists of a double-throat venturi provided with

FIG. 1.



Hooded two-throat venturi No. 1.

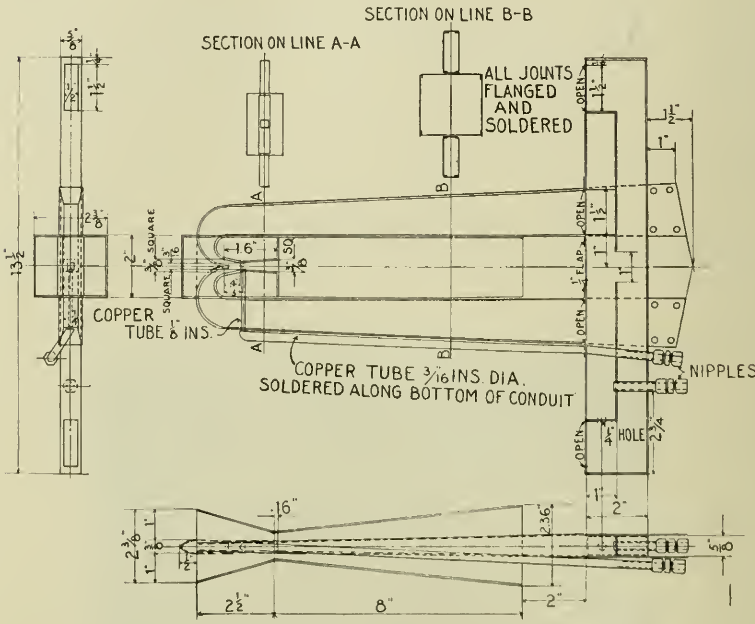
a dry air reservoir and flues leading therefrom to the interior of the smaller hooded venturi as shown.

The air rushing into the rectangular openings in the base of

* Communicated by A. F. Zahm, Ph.D.

the instrument comes almost to rest and generates nearly full impact pressure, while any water drops it may contain strike the rear wall, trickle down and run out the lower slot. Suitable baffle plates prevent any stray drops from reaching the flues. The dry air passing through these spacious flues enters the smaller cone of the interior venturi in symmetrical flow from opposite sides, and emerges rearward in the usual manner just at the throat of the larger surrounding venturi. Direct influx of the

FIG. 2.



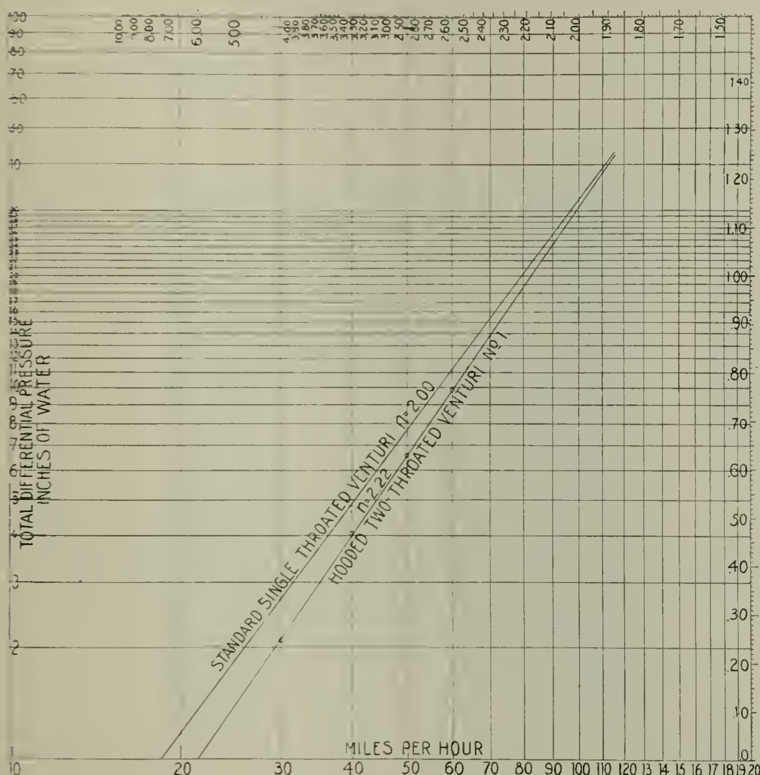

Plans for hooded two-throat venturi No. 1.

outer air into the smaller venturi is prevented by the stream-line hood shown protruding from the front. The large outer venturi is made in about the same proportions as an ordinary one, the throat area being about one-fourth that of the intake opening. The interior venturi also is made of the same proportions as an ordinary one. The impact pressure is collected from a nipple extending into the reservoir behind the baffle as shown. A tube leading from the throat of the smaller venturi collects the suction. The base of the instrument is provided with lugs for at-

tachment to a pole protruding from the car or rigging of the dirigible.

Figures 3 and 4 give the results of the wind tunnel tests; the first showing the differential pressure in terms of the wind speed; the second showing the fluctuation of the readings with variations of the wind direction in pitch and yaw.

FIG. 3.



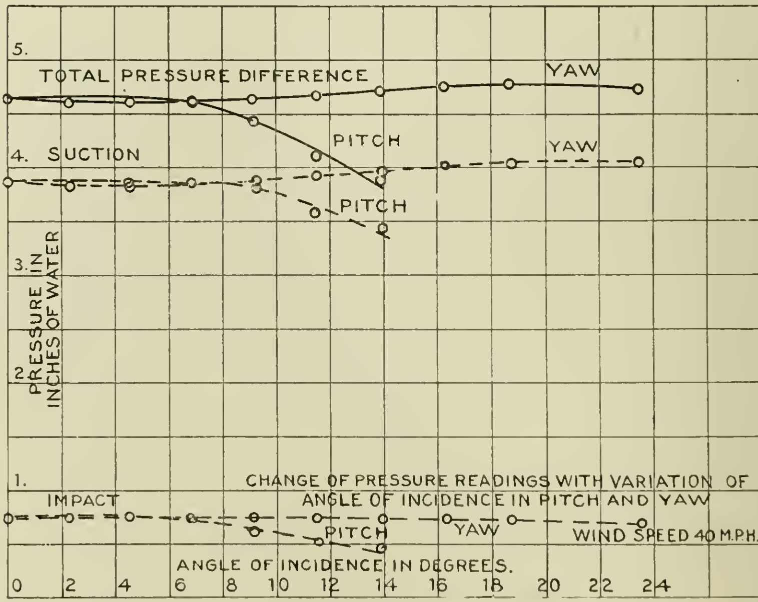

Calibration diagram for hooded two-throat venturi.

Figure 3 shows that the total differential pressure is 8.9 inches of water at 50 knots speed, and increases as the power 2.22 of the velocity. On the same diagram is shown the calibration curve for the Navy's standard single-throat venturi, whose readings increase as the square of the velocity. At the proposed dirigible speeds of 20 to 50 knots, the readings of the single-

throat instrument averages about 20 per cent. higher than those of the double-throat instrument. The latter could doubtless be made to read much higher than the single throater by suitably designing the flues; but this desideratum has been attained more simply in the second type mentioned.

Figure 4 presents the pressures in both the impact and suction nozzles—also their resultant pressure—for the various incidences in pitch and yaw. The resultant pressure diagram indicates a

FIG. 4.




Change of reading with change of wind direction, of hooded venturi No. 1

variation of about ½ per cent. from the mean reading, as the incidence varies 7° in pitch and yaw positive. Since the instrument is symmetrical in both vertical and horizontal planes through its axis the same readings should obtain for negative incidences. The lower dotted lines in the diagram indicate the impact pressure in the cistern, which is very approximately equal to $\rho v^2/2$. This taken from the total pressure differences gives the suction shown also by the dotted line.

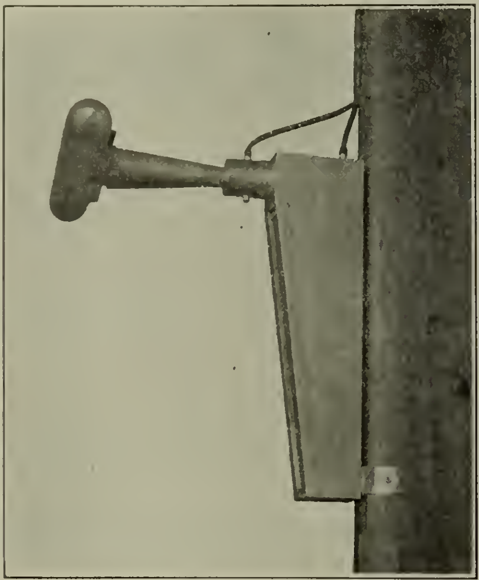
When this first type of double-throat instrument was used on the school dirigible at Akron in July, 1917, together with a

Foxboro pressure gauge, it was found to give sufficiently strong and uniform readings. But its manufacture was not recommended; first, because the instrument was unnecessarily heavy; secondly, because it was expensive to make; thirdly, it was difficult to build sufficiently uniform to give the same results in different instruments; lastly, it was superseded by a lighter and more powerful instrument.

PART II.

Figures 5 and 6 show the construction of the second instrument. In principle it consists of an ordinary double-throat ven-

FIG. 5.



Hooded two-throat Venturi No. 2.

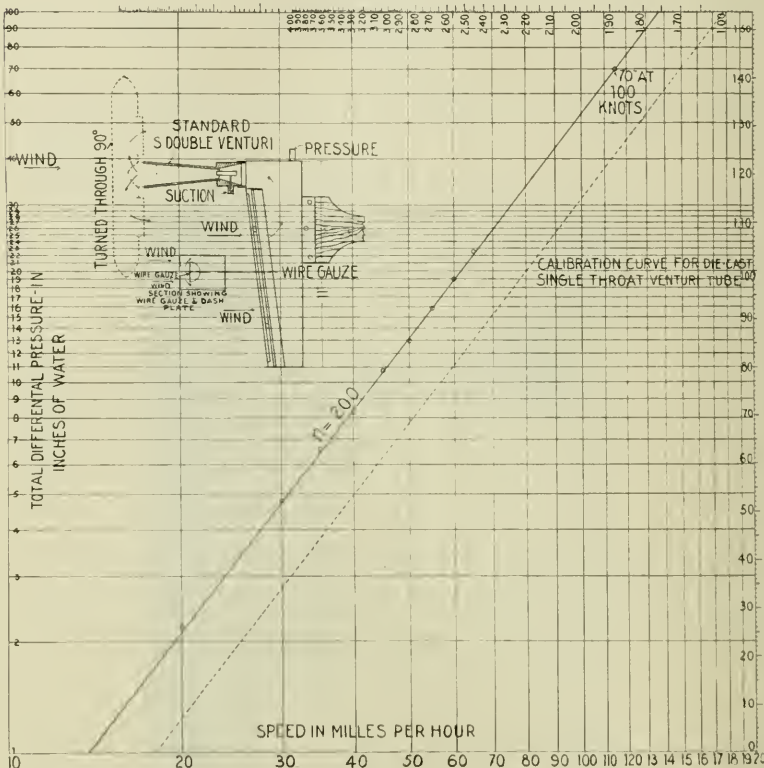
turi reversed in direction, its smaller end inserted in a dry air cistern, its larger end capped with a tee-tube which serves both to increase the suction and to shield the venturi from rain.

The wind driving into the rectangular slot of the cistern strikes against a wire screen designed to remove the rain drops; thence passes upward and forward through the regular venturi;

thence into the tee-pipe where it divides right and left, finally emerging from rectangular slots at the rear thereof.

Figure 6 presents the calibration curve of this instrument for all speeds from 20 to 70 M.P.H.; also that of the Navy's standard die-cast single-throat venturi, for comparison. In both,

FIG. 6.



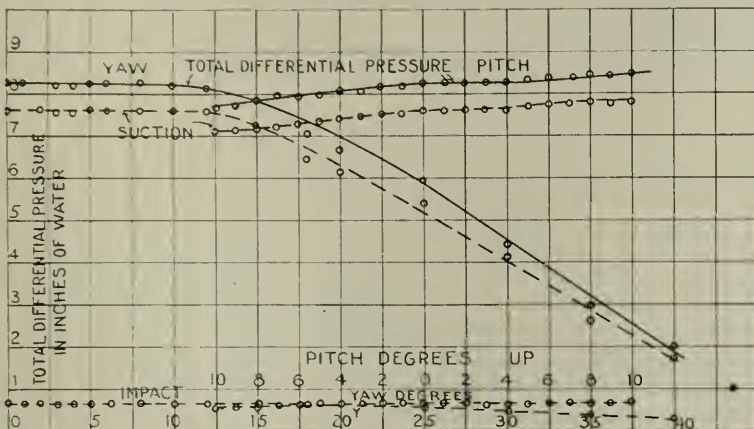

Plan and calibration line of hooded venturi No. 2.

the resultant pressure difference varies directly as the square of the velocity at all available speeds of the wind tunnel. At 100 knots the pressure difference is 41 inches of water for the single-throat instrument; 70 for the double-throat instrument with a rain-shield. Without the rain-shield the latter reading becomes 78, or nearly twice that for the single-throat instrument.

Figure 7 presents the resultant pressure difference at all in-

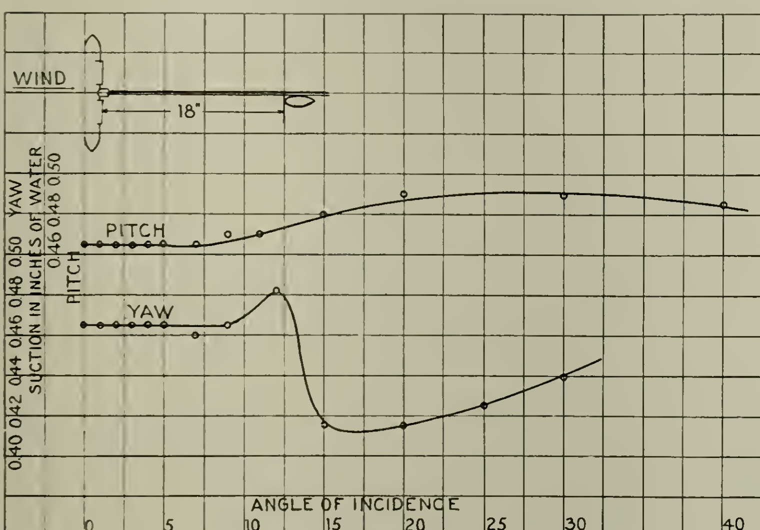
cidences in yaw from 0° to 40° positive; and the same may be expected for negative incidences, owing to symmetry; also the

FIG. 7.




Change of reading with change of wind direction, of hooded venturi No. 2.

FIG. 8.

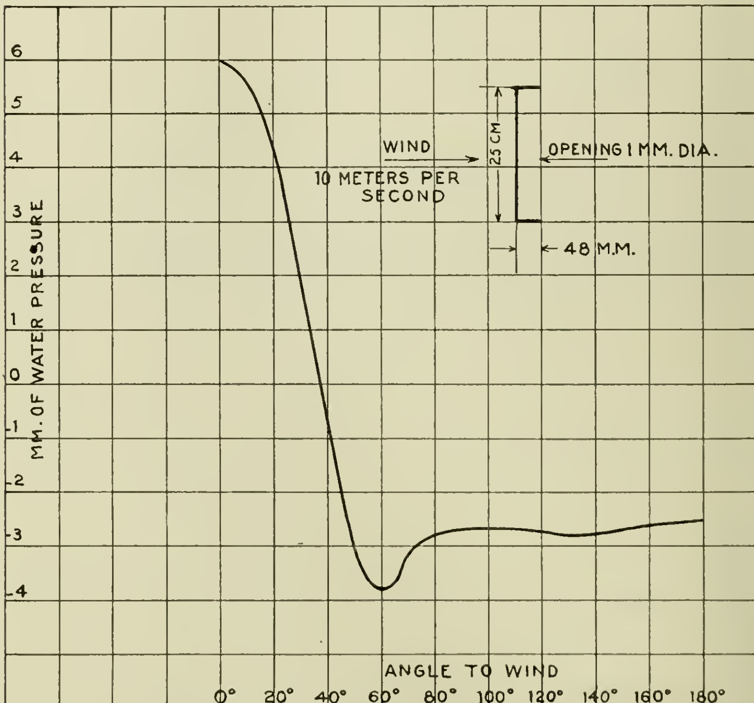



Suction at rear of tee-cap, at 40 miles an hour.

pressure differences for variations in pitch through 10° up and down. The yaw curve shows practically no variation in reading

for changes of incidence from 0° to 10°; the pitch curve shows an increase of pressure difference above the zero of slightly over one per cent. as the nose of the instrument is canted up 7°, and a decrease of 4 per cent. as the nose of the instrument is canted downward. This latter variation is doubtless due to the blanketing of the rectangular slot of the cistern, and might be

FIG. 9.




Suction at rear of cylinder found by Finzi and Soldati.

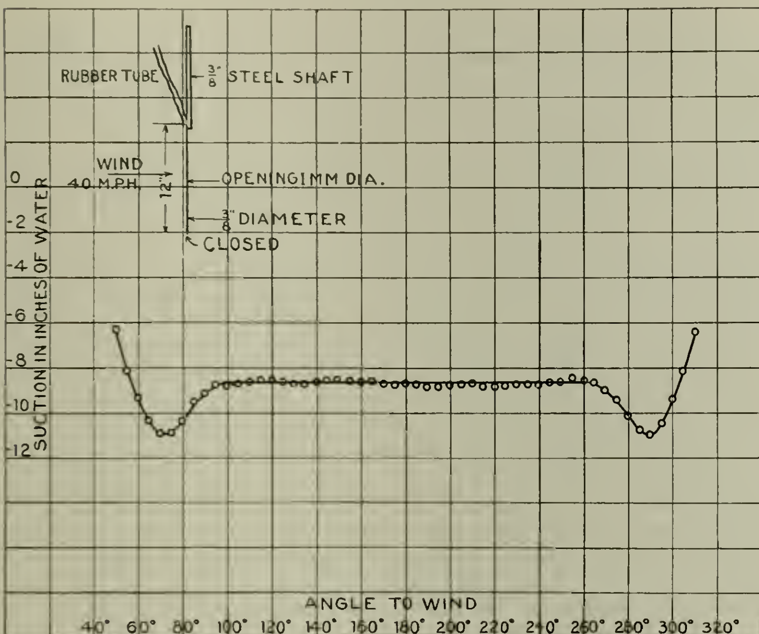
obviated by lowering the slot. The dotted line giving the impact pressure in the cistern bears out this latter statement, since it indicates constant impact for all angles in pitch except when the nose of the instrument is pointed downward 3° or more. Obviously a falling of the impact pressure entails loss of velocity through the venturi throat, and hence a loss of suction.

Figure 8 presents the suction readings of the tee-cap when placed alone in the wind tunnel, as shown in the sketch. This

diagram corroborates the results published by Doctors Finzi and Soldati in 1902 in their pamphlet "Esperimenti sulla Dinamica dei Fluidi," in which they show that the pressure distribution over the rear surface of a cylinder held squarely across the wind is approximately constant. They gave no readings, however, for a cylinder held oblique to the wind.

Figure 9 presents the data of Finzi and Soldati; Fig. 10

FIG. 10.




Suction behind cylinder 12 inches long by ⅜ inches diameter.

the data obtained in this research; for the pressure distribution over a meridian circle of a cylinder held squarely across the wind, as in the sketches.

The data of Fig. 9 were obtained with a cylinder 25 cm. long by 48 mm. diameter, held with the perforation facing first directly into the wind, then at various angles away from the wind all the way to 180°. The pressure is seen to be approximately constant over the rear portion of the cylinder to a distance of about 90° on either side of the exact rear.

Fig. 10 shows a still more exactly constant pressure over all the rear portion of the cylinder lying within about 80° on either side of the exact rear. The tube employed in this experiment was 12 inches long by 3/8 inch diameter, having a one millimetre opening for collection of the pressure.

A few of these speed nozzles were placed on dirigibles and kite-balloons during the war, and were found to give satisfactory service.

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**War Materials, Nitrogen Fixation and Sodium Cyanide.**—Under this title the Department of the Interior, Bureau of Mines, has published a bulletin giving brief accounts of the efforts of the United States authorities to supply from domestic sources those raw materials that are needed for the great industries, especially the war industries, and for which in pre-war times we had been largely, and in some cases almost wholly, dependent on importations. The difficulty consisted not merely in the shutting off of the supply from the countries at war, but the shortness of tonnage, and the need of it for transportation of troops and supplies, still further emphasized the importance of domestic sources. Among the raw materials that were especially the subject of these efforts are manganese, graphite, tin, mercury, potash, tungsten, molybdenum, antimony, chromite, magnesite, mica, platinum and arsenic. The work in regard to some of these has been considered in this JOURNAL, but several other items may be briefly discussed.

Acts of Congress constituting commissions and boards of experts were passed and many eminent engineers and chemists undertook investigations for deposits of the minerals from which the important products might be obtained. Studies were also made in regard to the several processes of nitrogen fixation. The bulletin in hand is a preliminary report; in fact, is merely an advance chapter from Bulletin 178 of the Bureau of Mines.

One point of interest is worthy of special notice, namely, that the simple process of Bucher for the production of sodium cyanide has been shown to be practicable on the large scale.

In this connection notice should be given of the success of methods devised by L. S. Potsdamer for recovering valuable materials from gas-mass; that is, the mixture of ferric hydroxide and wood chips used for purifying illuminating gas. This accumulates a number of by-products, among which are tar, sulphur, thiocyanides, ammonium salts, ferro- and ferricyanides, double ammonium cyanides. Potsdamer devised a plan of recovering these substances and reviving the gas-mass so that it could be returned to the purifiers. The details of the methods will be found in *Jour. Ind. Eng. Chem.*, vol. xi, p. 769, 1919.

H. L.

# EXPERIMENTS ON SO-CALLED "ROOT-BEERS."*

BY

CHARLES H. LaWALL, Ph.M., AND HENRY LEFFMANN, M.D.,

Members of the Institute.

THE adoption of drastic prohibitory methods in the United States has led to considerable discussion as to the relation between the alcohol content of standard beers and the household products such as "root-beer," "spruce-beer" and "mead." In judging of these latter forms it must be borne in mind that they are never used for true intoxication, but for their effervescent properties and the special flavors. The forms sold already bottled or drawn from fountains and used immediately are non-alcoholic, but the household production of an effervescing beverage can best be conducted by the fermentation of ordinary sugar with yeast. If such a mixture be made and kept at room temperature for a few days in an open vessel a notable amount of alcohol will be produced, but the liquid will be quite unfit for beverage purposes. To secure the effervescence the fermenting liquid must be bottled soon after the fermentation starts. As a rule the alcohol does not go above 1 per cent. after five or six days of fermentation under pressure. Statements in conflict with this having been made lately in connection with discussions of the bearing of the prohibition acts, we have deemed it worth while to repeat some experiments made by us some time ago, and submit figures. The alcohol was determined after distillation by the immersion refractometer, the reducing sugar gravimetrically by Fehling's solution. Polarimetric readings were also made. The mixture was made up in accordance with the directions given for one of the best known root-beers. The bottles were filled to within a small distance of the cork, and kept at room temperature during the latter part of July. The figures were obtained as follows:

| | Reducing sugar | Alcohol by volume | Effervescence |
|---|---|---|---|
| When mixed .................. | 0.20 | none | none |
| After 24 hours ................ | 7.7 | 0.20 | very slight |
| After 3 days .................. | 6.9 | 0.39 | slight |
| After 5 days .................. | 5.9 | 0.82 | marked |
| After 8 days .................. | 5.2 | 1.18 | marked |

* Communicated by the Authors.

The polarimetric readings were irregular and showed fluctuations in which the minus readings increased while the reducing sugar decreased, due doubtless to the fact that the dextrose is more readily fermented by ordinary yeasts than levulose. A second series resulted as follows:

| | Reducing sugar | Alcohol by volume |
|---|---|---|
| When mixed | 0.19 | none |
| In 24 hours | 8.8 | 0.20 |
| In 3 days | 8.0 | 0.49 |
| In 5 days | 7.1 | 0.79 |
| In 8 days | 6.5 | 1.10 |

This series was kept at room temperature for three days then placed in a uniformly cool place (40° to 50° F.) for the remainder of the time.

No appreciable alcohol was obtained if the sample was placed in a cool room (40° to 50° F.) three hours after bottling, while the fermentation seemed to be active. The action seemed to be promptly checked, the alcohol not rising above 0.35 per cent. and the effervescence so slight as to make the product of little palatability.

These experiments, which agree with those obtained previously by us, indicate that when the product has attained sufficient sparkle to be agreeable, the alcohol ranges from 0.4 per cent. to 0.8 per cent. by volume. If the fermentation is allowed to go until more than 1.25 per cent. of alcohol is formed the liquid becomes unpalatable from the diminution of the sugar and the increase of yeast.

It also seems that in well-corked bottles the fermentation will not proceed so far as to produce 2 per cent. of alcohol by volume.

## NOTES FROM THE U. S. BUREAU OF STANDARDS *

### PHOTOELECTRIC SPECTROPHOTOMETRY BY THE NULL METHOD.[1]

By K. S. Gibson.

[ABSTRACT.]

In connection with the color standardization work of the National Bureau of Standards [2] it is desired to have available a number of independent methods of making spectrophotometric determinations, especially in the visible part of the spectrum; for it is generally admitted that the fundamental basis of color specification is spectrophotometry. To supplement the other methods at present in use at the Bureau and especially to overcome the well-known uncertainty of measurements by these other methods in the blue and violet, the author in 1917 was given the problem of developing a method for accurate and convenient photoelectric spectrophotometry suitable for routine determinations. This was especially desirable for the measurement of spectral transmission. The sensitive potassium-hydride photoelectric cells now on the market (made by Kunz) when used with an incandescent lamp and a glass dispersing prism, give a maximum response usually near 460 millimicrons, and are thus very suitable for the purpose. The making and assembling of apparatus was completed in April, 1918; and since that time it has been in continual use, being very satisfactory as to speed of operation, ease of keeping in working condition, and accuracy of measurement.

In the null method as used, two photoelectric cells and the proper batteries are connected in a sort of Wheatstone bridge arrangement,[3] with the electrometer as the indicator. Radiant energy from a 600-watt Mazda C moving-picture lamp, after dis-

* Communicated by the Director.

[1] Scientific Paper No. 349.

[2] I. G. Priest, "The Work of the National Bureau of Standards on the Establishment of Color Standards and Methods of Color Specifications." *Trans.* I. E. S., xiii, p. 38, 1918.

[3] F. K. Richtmyer, *Phys. Rev.*, (2) vi, p. 66, 1915.

persion through a Hilger constant deviation spectrometer, is incident upon one of the photoelectric cells. Radiant energy from a 14-watt Mazda C lamp is incident on the other photoelectric cell. The photoelectric currents generated in the two cells by the radiant energy from the two lamps tend to nullify each other so far as charging the electrometer is concerned; and by proper adjustments, the two currents may be made exactly equal, the zero motion of the spot of light from the electrometer indicating the balanced condition.

Measurements of the spectral transmission of a specimen are made by observing at any desired wave length the distances of the 600-watt lamp from the spectrometer slit necessary to obtain a balance of the electrometer with and without the specimen in position, all other factors such as slit widths, currents, etc., being kept constant. The ratio of the squares of these two distances respectively is the transmission. By this use of the null method all errors are eliminated, as well as the necessity of any kind of calibration, in connection with the relation between photoelectric current and incident radiant power, with the dark currents through the photoelectric cells, and with electrometer deflection methods.

The accuracy has been tested in various ways, chief of which are the measurements of rotating sectors of known transmission and comparisons with values obtained by other methods. It is considered that the uncertainties of values obtained from 410 to 550 millimicrons, inclusive, are not greater than 0.01 for any values of transmission between 0.00 and 1.00 and not greater than 0.003 for transmissions between 0.00 and 0.10. Beyond these wave lengths just given, as far as 390 and 600 millimicrons, inclusive, the uncertainties of measurement are not greatly increased, being at 390 and 600 not more than twice as great as throughout the better range. Measurements can be made from 380 to 650 millimicrons.

The apparatus has also been used for the measurement of spectral diffuse reflection relative to that of a standard such as magnesium carbonate, and is adapted to the measurement of the relative distribution of radiant power of two sources, to the measurement of fluorescence, and to extension into the ultraviolet if quartz parts instead of glass were used.

## USE OF A MODIFIED ROSENHAIN FURNACE FOR THERMAL ANALYSIS.[4]

By H. Scott and J. R. Freeman, Jr.

[abstract.]

Rosenhain in 1915 published a description of a furnace for the thermal analysis of metals operating under a new principle. Instead of varying the temperature of the furnace containing the specimen under investigation, he heated the furnace so as to produce a uniform temperature gradient along its length and moved the specimen through the furnace. The present paper describes in detail some improvements in the design of his furnace and considers certain features of its operation. A simple method of mounting is described which gives highly satisfactory results using specimens of less than 2 grams weight.

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## THE HEAT TREATMENT OF DURALUMIN.[5]

By P. D. Merica, R. G. Waltenberg, and H. Scott.

[abstract.]

The heat treatment of alloys of the type, duralumin, was investigated and the effect observed of variations in the heat treating conditions, such as quenching temperature, temperature of quenching bath and of aging or tempering, and time of aging upon the mechanical properties.

Conclusions are drawn relative to the best conditions for commercial heat treating practice for this alloy. The temperature of quenching should not be above that of the $CuAl_2$ aluminum eutectic, which is usually about 520° C., but should be as near to this as possible without danger of eutectic melting. The pieces should be held at this temperature from 10 to 20 minutes and quenched preferably in boiling water. The hardening may for most purposes best be produced by aging for about 5 days at 100° C.

A theory of the mechanism of hardening of duralumin during aging after quenching from higher temperatures was de-

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[4] Scientific Paper No. 348.

[5] Scientific Paper No. 347.

veloped which is based upon the decreasing solubility of the compound $CuAl_2$ in solid solution in aluminum with decreasing temperatures from 520° to ordinary temperatures. It is believed that the precipitation of excess $CuAl_2$, which is suppressed by quenching, proceeds during aging, the precipitation taking place in very highly dispersed form. The hardening is due to the formation of this highly dispersed precipitate.

According to this theory the hardening of duralumin during aging or tempering after quenching presents a very close analogy with that of steel, and the evidence in support of the theory is of the same nature and of approximately the same competence as that in support of the prevailing theory of the hardening of steel.

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## CONSTANT TEMPERATURE STILL HEAD FOR LIGHT OIL FRACTIONATION.[6]

By Frederick M. Washburn.

[ABSTRACT.]

This paper represents the results of a brief search for an improved method for the determination of benzine, toluene, and solvent naphtha in light oil.

The three types of methods generally in use for the fractionation of light oil for the determination of benzine, toluene, and solvent naphtha are discussed. An apparatus which is an improvement on the dephlegmator of the Wilson and Roberts still is described, and the details of its operation are given. The apparatus is easily and inexpensively constructed, and requires no greater attention or time than others used. Exceptionally large volumes of "pure" fractions are obtained which have a very small boiling point range, showing that they contain only negligible amounts of impurities. Almost all of each of the components of the mixture distilled is obtained in practically the pure state, since the volumes of each of the intermediate fractions are only about 1.5 per cent. of the volume taken for distillation. The composition of each of the intermediate fractions is actually determined, and the error introduced by this determination is small,

[6] Technologic Paper No. 140.

since it is applied to only small volumes. The apparatus works well on mixtures containing widely varying percentages of benzine, toluene, and solvent naphtha.

## KITCHEN CARD OF HOUSEHOLD WEIGHTS AND MEASURES.[7]

[ABSTRACT.]

The tables of weights and measures most useful for household purposes are being published on a card designed to be hung in the kitchen where it can be easily referred to.

The card contains tables of liquid measure, dry measure, avoirdupois weights, linear measure, square measure and cubic measure. Rules are given for calculating the area of the rectangle, circle, and cylinder and the volumes of some common geometrical figures. The approximate weights of many commodities used in the household and particularly in the kitchen, are included.

## NOTICE REGARDING BIBLIOGRAPHY OF HELIUM LITERATURE.[8]

By E. R. Weaver.

[ABSTRACT.]

The year 1918 marks the beginning of a new era in the history and use of helium. Before that time only a few litres of the gas had been collected and the cost per litre was enormous. During the war the development of great factionating plants capable of separating from natural gas a sufficient quantity of helium to supply a fleet of airships has aroused the keen interest, not only of engineers and scientists, but also of the general public in the unique properties of this gas.

A bibliography of the scientific literature relating to helium was prepared for use during the war and is now published as Circular 81 of the Bureau of Standards. This bibliography will serve as a guide to the subject and stimulate research by pointing out the sources of scientific data concerning helium.

[7] Miscellaneous Publication No. 39.

[8] Circular 81.

Related papers are grouped together in their chronological order, making the bibliography, in effect, a brief outline history of the subject.

## REFLECTION POWER OF STELLITE AND LACQUERED SILVER.[9]

By W. W. Coblentz and H. Kahler.

[abstract.]

It is shown that the reflectivity of stellite varies somewhat in the visible spectrum, depending upon the homogeneity and no doubt upon the exact composition of the alloy.

Data are given on the reflecting power of lacquered silver mirrors, before and after exposure to ultra-violet light. It is shown that owing to photochemical action in the lacquer, the silver is turned brown in color, thus reducing its reflecting power.

## THE LOCATION OF FLAWS IN RIFLE BARREL STEEL BY MAGNETIC ANALYSIS.[10]

By R. L. Sanford and Wm. B. Kouwenhoven.

[abstract.]

This paper describes an investigation which was undertaken for the purpose of determining whether an application of magnetic analysis was practicable for the detection of flaws in rifle barrel steel. By means of apparatus especially constructed for the purpose a large number of bars were explored for magnetic uniformity along their length. In spite of the fact that these bars were taken from material which had previously been rejected as the result of drilling tests, not one was found which contained a pipe. The results obtained, however, demonstrated that the method is amply sensitive to detect and locate flaws. Further study is necessary to determine to what degree the sensitivity of the apparatus should be reduced in order not to cause the rejection of material which is satisfactory for all practical purposes and also to determine the type and magnitude of the effect which

[9] Scientific Paper No. 342.
[10] Scientific Paper No. 343.

will be produced by a pipe. For this reason the work is being continued by the Winchester Repeating Arms Company who coöperated in the investigation and at whose plant the apparatus has been installed.

## MEASUREMENTS OF WAVE LENGTHS IN THE SPECTRA OF KRYPTON AND XENON.[11]

By Paul W. Merrill.

[ABSTRACT.]

This paper records photographic measurements of wave lengths in the spectra of krypton and xenon, principally in the red and infra-red. In krypton 37 new lines were measured between 6576 A and 8928 A, in xenon 52 lines between 6318 A and 9162 A. In this region there are numerous strong lines which are probably among the most important in the spectra of these elements. Notable among these are xenon lines at 8231 and 8280. These and other lines may be of value as wave-length standards in the infra-red.

Attention is called to a probable analogy between the spectra of the rare gases neon, argon, krypton, and xenon which this investigation has brought to light.

## RECOMMENDED SPECIFICATION FOR LINSEED OIL, RAW, REFINED AND BOILED.[12]

[ABSTRACT.]

Prepared and recommended by the U. S. Interdepartmental Committee on Standardizing Paint Specifications, April 16, 1919. This Committee was appointed at the suggestion of the Secretary of Commerce and consisted of representatives of the War, Navy, Agriculture, Interior, Post Office, Treasury, and Commerce Departments, the Railroad Administration, the Panama Canal, and the War Service Committee of the Paint Manufacturers' Association of the United States. The Committee submitted a preliminary draft of this specification to more than 300

[11] Scientific Paper No. 345.

[12] Circular 82.

representatives of the paint and varnish industries, including all of the large manufacturers of linseed oil, and gave careful consideration to the large number of replies received in time.

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## OXYGEN CONTENT BY THE LEDEBUR METHOD OF ACID BESSEMER STEELS DEOXIDIZED IN VARIOUS WAYS.[13]

By J. R. Cain and Earl Pettijohn.

[ABSTRACT.]

It is shown that the Ledebur method for determining oxygen in steels indicates no marked difference in oxygen contents of steels practically identical as to chemical composition and heat treatment, but made by different deoxidation treatments. Some differences in physical properties of such steels are shown.

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## THE BEHAVIOR OF WROUGHT MANGANESE BRONZE EXPOSED TO CORROSION, WHILE UNDER TENSILE STRESS.[14]

By P. D. Merica and R. W. Woodward.

[ABSTRACT.]

Specimens of wrought manganese bronze rods were exposed in special steel test frames to corrosion in water and moist air while at the same time under tensile stress with the object of determining the maximum safe stresses for this material under these conditions. While the period of exposure was only two years and the initial condition of the best bars not normal in that the initial stresses had been removed by a low temperature anneal, the results of the tests are capable of some general interpretations.

None of the test bars fractured within this period under stresses below the proportional limit, and four of the bars withstood corrosion during this period under stresses which produced slight yielding and permanent set when first applied.

Fracture did not occur under stresses less than 35,000 pounds per square inch.

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[13] Scientific Paper No. 346.

[14] Technologic Paper No. 135.

One specimen with a proportional limit of 35,000 pounds per square inch fractured under a tensile stress of approximately 40,000 pounds per square inch, and another with a proportional limit of 42,500 pounds per square inch, under a stress of approximately 43,000 pounds per square inch.

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## APPLICATION OF THE INTERFEROMETER TO GAS ANALYSIS.[15]

By Junius David Edwards.

[ABSTRACT.]

One of the most useful of the physical methods applicable to gas analysis is that of gas interferometry. By the application of a new method of calibration, previously described in Scientific Paper No. 316, the use of the gas interferometer has been simplified and extended. The relation betwen the refractivities of the gases and the indications of the interferometer is discussed for various typical cases and illustrative calculations given. The determination of helium in a mixture of gases is one case of interest which is discussed. It is of importance because of the scarcity of analytical methods for determining helium. Other cases discussed are the effects of variations in the composition of air where it is a component of mixtures under test, the analysis of flue gases, the relative sensitivity of the interferometer for different gases and points about the operation of the interferometer.

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## EXPERIMENTAL-RETORT TESTS OF ORIENT COAL.[16]

By R. S. McBride and I. V. Brumbaugh.

[ABSTRACT.]

The Bureau of Standards in connection with coke-oven investigations found it desirable to carry out a short series of experimental-retort tests of Illinois coal to determine the influence of temperature of coking upon the characteristics of the

[15] Technologic Paper No. 131.

[16] Technical Paper No. 134.

coke and quantity and quality of gas produced. This work was done at the Sparrows' Point plant of the Bethlehem Steel Company, where apparatus was placed at the disposal of the Bureau through the courtesy of the engineers in charge.

The gas produced at high temperatures was much greater in volume but lower in heating value than that produced at the lower temperatures, not only because of more complete elimination of volatile matter from the coal, but also as a result of the greater decomposition of the heavier volatile matter into gaseous constituents at the higher temperature. At the lower temperatures the coke was very inferior to that produced at the higher temperatures, but in no case was the temperature maintained as high as is generally used in coke-oven practice.

Detailed results for the series of five tests are given, and a separate series of results on other coals is included, furnishing data given to the Bureau by the Steel Company covering tests made with the same apparatus during the preceding two years.

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## AIRPLANE ANTENNA CONSTANTS.[17]

By J. M. Cork.

[ABSTRACT.]

THIS paper contains data observed by the writer while an officer in the Signal Corps, U. S. Army, and is published by permission of the Chief Signal Officer.

The purpose of this work was to devise a method for measuring airplane antenna constants (*i.e.*, capacity, inductance, natural wave length) under conditions of actual flight; and to use this method to obtain data on various forms of fixed and trailing wires.

The principle of the method involves a continuous wave oscillator feeding directly into the antenna and substituting for the antenna a variable calibrated condenser and adjusting for the same wave length as with the antenna in the oscillating circuit. The result obtained is the effective capacity of the antenna. Having found this, a variable calibrated non-inductive resistance is varied until the D. C. component of the plate current reads the

[17] Scientific Paper No. 341.

same as for the real antenna. This gives the effective antenna resistance. Knowing the effective values of capacity at various wave lengths, the true capacity, inductance and natural wave length are readily found.

By this method results were obtained with various forms of fixed wires, and one, two and four trailing wires of various lengths are summarized.

A method for finding the directional transmitting effect of various antennas is also described. In order to compare the amounts of energy received, a detector tube with a three-stage audio amplifier is used. A transformer is placed in the plate circuit of the last amplifier tube, the secondary of which is connected to the heater coil of a thermocouple connected to a D.C. micro ammeter. This when calibrated is free from many of the uncertainties of the ordinary audibility meter. A typical directional curve of the trailing wire antenna is included in the paper.

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## EFFECTS OF GLUCOSE AND SALTS ON THE WEARING QUALITY OF SOLE LEATHER.[18]

By P. L. Wormeley, R. C. Bowker, R. W. Hart, L. M. Whitmore, and J. B. Churchill.

[abstract.]

Technologic Paper No. 138, Bureau of Standards, on the "Effects of Glucose and Salts on the Wearing Quality of Sole Leather," contains a description of the methods used and the results obtained from the first of a series of tests to be made on this subject. Four brands of leather were tested; two tannages to which very small amounts of glucose and salts were added and two tannages to which larger amounts of these materials were added. The experimental work consisted of actual service tests on shoes, tests on a laboratory wearing machine, water absorption tests and complete chemical analyses of the original and worn leathers. Results are presented which show the variation in wear of the different leathers, the variation in wear of soles cut from different locations on the hide, the water-absorption qualities of the leathers and the variation in chemical composition

[18] Technologic Paper No. 138.

of the leathers in different parts of the hide for both the new and worn soles. From the results of the test there is no indication that the addition of glucose and salts is either beneficial or detrimental to the durability of the leather and it is conclusively shown that the greater part of the added glucose and salts was lost from the leather during wear while the other water-soluble materials appear to be retained in the leather.

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## A COMPARISON OF THE HEAT-INSULATING PROPERTIES OF MATERIALS USED IN FIRE-RESISTIVE CONSTRUCTION.[19]

By Walter A. Hull.

[ABSTRACT.]

A COMPARISON of the relative efficiencies of the different classes of materials commonly used in fire-resistive construction to protect load-bearing members from the heat of an accidental fire has recently been made in an investigation by the Bureau of Standards. All materials were made up into specimens in the form of solid cylinders, 8 inches in diameter and 16 inches long. These were tested separately in a specially designed gas fired furnace, the furnace temperature being raised gradually to 927° C. in ninety minutes and held at approximately that point for two hours.

Temperatures were measured by means of thermocouples at four points in the interior of each specimen. The temperatures were recorded throughout each test, giving information as to the rate of heat penetration in each sort of material. The condition of specimens after the test gave information as to the extent of deterioration which took place in each kind of material due to the heat.

The investigation included three clays that are used for the manufacture of terra cotta tile, concretes from two mixtures, 1:2:4 and 1:3:6, with a number of different coarse aggregates, gypsums of several different mixtures from raw materials from different parts of the country, and lime mortar.

The most rapid heat penetrations were found in the denser specimens of the burned clays. A porous burning clay, light burned, heated through as slowly as most of the concretes and

[19] Technologic Paper No. 130.

much less rapidly than the denser, harder burned clays. No clay specimens of the porosity of terra cotta lumber produced by the addition of sawdust were included.

Among the concretes, those with a coarse aggregate of gravel and those from bituminous cinders containing a large proportion of combustible material heated through most rapidly. Concretes from clean bituminous cinders, trap rock and blast furnace slag heated through more slowly, while the limestone concrete specimens heated through somewhat more slowly than any of the others. The less rapid temperature progress in the limestone concrete specimens may be attributed to the heat absorbed by the decarbonation of the limestone in a thin layer of concrete next to the exposed surface and to the fact that the resulting calcium oxide was presumably a better heat insulator than the original stone.

Gypsum specimens showed long temperature lags at about 105° C., due to dehydration of the material. Temperature progress through the gypsum specimens was much slower than through the clays and concretes. The densest, heaviest gypsum mixture heated through slightly more slowly than the lighter ones, due presumably to the great heat-absorbing capacity of the heavier specimens.

Lime mortar made a favorable showing, thermally, as compared with the concretes.

All the concretes were weak after test. Limestone concretes retained somewhat more strength than those from other coarse aggregates, though the cinder concretes were tougher than the others. The gravel concretes were the weakest of all after test. This is attributed largely to the fact that the gravel was made up of quartz and quartzose materials, as it is known that the expansion behavior of quartz, including the sudden volume increase as the inversion point at 575° C. is approached, is especially conducive to destructive strains. The gypsum and the lime mortar retained very little strength after the test.

The results are consistent with earlier information as to the relative termal qualities of the three classes of materials, burned clays, concretes, and gypsums, but are favorable to members of each class; namely, porous clays, limestone concretes, and the denser gypsums. The showing of gravel concrete both thermally and in respect to loss of strength was unfavorable.

## THE DETERMINATION OF FREE CARBON IN RUBBER GOODS.[20]

By A. H. Smith and S. W. Epstein.

[ABSTRACT.]

The method is briefly as follows: Extract a 1-g sample for six hours with acetone and then for three hours with chloroform or carbon bisulphide. Transfer the sample to a 250-cm³ beaker and heat on the steam bath until it no longer smells of chloroform. Add a few cm³ of hot concentrated nitric acid and allow to stand in the cold for about 10 minutes. Add 50 cm³ more of hot concentrated nitric acid, taking care to wash down the sides of the beaker. Heat on the steam bath for about one hour or until all bubbles or foam disappear from the surface. Pour the liquid, while hot, into a Gooch crucible containing a thick pad of ignited asbestos. Filter by slowly applying gentle suction and wash well with hot concentrated nitric acid. Empty the filter flask and wash the filter alternately with acetone and benzol until the filtrate is colorless. Next wash it well with a hot 15 per cent. solution of sodium hydroxide. Test for the presence of lead by running some warm ammonium acetate solution, containing an excess of ammonium hydroxide, through the pad into a solution of sodium chromate. If a yellow precipitate forms, the pad must be washed with the ammonium-acetate solution until the washings no longer precipitate the sodium-chromate solution. Next wash the residue a few times with hot concentrated hydrochloric acid and finally with warm 5 per cent. hydrochloric-acid solution. Remove the crucible from the funnel, taking care that the outside is clean, and dry it in an air bath for one and one-half hours at 150° C. Weigh, burn off the carbon at a dull-red heat, and reweigh. The difference in weight represents approximately 105 per cent. of the carbon originally present in the form of lampblack or gas black. It is recommended that 0.5-g samples be taken for compounds containing over 10 per cent. of free carbon and 1-g samples for compounds containing less than this amount. It is also unnecessary to extract high-grade compounds.

After a brief review of the literature, a discussion is given of the difficulties encountered in the use of the nitric acid method.

[20] Technologic Paper No. 136.

It is shown that nitric acid attacks the carbon and gives an insoluble compound, with the result that a factor of 1.05 must be used. An experiment is outlined which is taken to prove that bituminous matter is all removed by the treatment indicated. The effects of various mineral constituents are discussed and methods are outlined for their removal.

The authors conclude that, though the attack of nitric acid on carbon makes a very accurate determination impossible, the error caused thereby when the factor 1.05 is used is sufficiently small to justify the use of this method at the present time as a routine one in the rubber laboratory.

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## THE MECHANICAL PROPERTIES AND RESISTANCE TO CORROSION OF ROLLED LIGHT ALLOYS OF ALUMINUM AND MAGNESIUM WITH COPPER, WITH NICKEL AND WITH MANGANESE.[21]

By P. D. Merica, R. G. Waltenberg, and A. N. Finn.

[ABSTRACT.]

Light aluminum alloys of several compositions belonging to each of the three ternary series: aluminum-magnesium-copper, aluminum-magnesium-manganese, and aluminum-magnesium-nickel, were rolled out into sheet and tested in tension as cold-rolled, after annealing, and after heat treatment, consisting of quenching from about 500° C. and aging at ordinary temperature.

The alloys of the aluminum-magnesium-copper series were superior in all conditions to those of the other series, in respect to tensile properties.

The tensile properties of the aluminum-magnesium-copper series may be much improved by appropriate heat treatment. The alloys of the aluminum-magnesium-nickel series are also improved by heat treatment, but not in the same degree as the former series. The alloys of the aluminum-magnesium-manganese series are not improved by heat treatment.

Samples of representative compositions of each series were exposed to corrosion in the salt spray test, and the appearance of samples observed after one and after two months' exposure to the action of the salt spray.

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[21] Technologic Paper No. 132.

The alloys of the aluminum-magnesium series resisted corrosion in general better than those of the other series, and this agrees with other experience in the corrosion of such alloys. The heat-treated specimens of the aluminum-magnesium-copper series were, however, but little inferior to those of the manganese series in their resistance to corrosion; the annealed and the cold-rolled samples of that series were the least resistant to corrosion of any of the alloys tested. Hard-rolled commercial aluminum corroded much more than any of the alloys. Annealed aluminum was more resistant to corrosion than the hard-rolled aluminum but did not compare favorably with most of the alloys.

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## TESTS OF FLEXIBLE GAS TUBING.[22]

By R. S. McBride and Walter M. Berry.

[abstract.]

A large number of accidents in recent years, resulting in loss of life and property, have been caused by the poor quality and the improper and careless use of flexible gas tubing. Some states have prohibited the use of such tubing and there has been increasing agitation, by fire prevention authorities and others who are active in the cause of safety, for greater restrictions in the use of this material.

The Bureau of Standards has made tests on about thirty typical varieties of tubing and the tests show that much of the material on the market is made of paper, covered with some tar compound, and in whole of such dangerous construction that some steps should be taken immediately to prohibit the use of such tubing.

There are several varieties of tubing that, if used with ordinary care, can be considered safe for all ordinary use; and the life of the better varieties is so much greater that it is really cheaper in the end. Much of the danger in gas tubings comes from the poor grade of rubber end pieces, and the tests showed that there was as great a variation in the quality of these as in the quality of the tubings themselves. One high-grade sample which probably would not increase the cost of the tubing more

[22] Technical Paper No. 133.

than a few cents showed ten times the tensile strength and percentage elongation at break of that of the cheaper samples.

The experiments cover tests of transverse strength; tensile strength; pull required to remove end piece; tightness when straight, bent, or twisted; pressure loss; flexibility; heating test; rubber slip ends; and detachable metal end-pieces.

The American gas engineers have realized that the interests of the gas industry require the production of a safe gas tubing and as a result the National Commercial Gas Association and the American Gas Institute working in conjunction formulated a set of tentative specifications and presented them at the 1916 meeting of these societies. The tests reported by the Bureau have been made along the lines suggested by these proposals and the results are discussed to show where, in the judgment of the Bureau, these tentative specifications are too rigid, where too lenient, and to what extent these specifications fulfill their purpose, *i.e.*, of providing safe, convenient, and commercially suitable tubing.

Before final adoption of specifications either by the gas associations or the Bureau of Standards for the National Gas Safety Code, it is anticipated that coöperation in this work will enable the Bureau and the associations to formulate mutually satisfactory standards so that the specifications which are finally adopted may be identical. As a step toward this highly desirable end, a report of these tests has been prepared and is now presented to bring out the further discussion which is essential before more definite recommendations are made.

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## THE SPECTRAL PHOTOELECTRIC SENSITIVITY OF SILVER SULPHIDE AND SEVERAL OTHER SUBSTANCES.[23]

By W. W. Coblentz and H. Kahler.

[ABSTRACT.]

This paper gives data on the change in the electrical resistance of the sulphides of silver and of bismuth, when exposed to radiations of wave lengths extending from 0.6$\mu$ to 3$\mu$. Measurements were made also upon galena, cylindrite, pyrites and jamesonite,

[23] Scientific Paper No. 344.

which, however, did not show photoelectrical sensitivity for the highest spectral radiation intensities available.

Both the natural mineral, acanthite, $Ag_2S$ and a laboratory preparation were examined. The latter material, which was hammered into a thin plate, was found insensitive photoelectrically, at room temperature. But at $-157°$ C. a sharp maximum of photoelectrical sensitivity was observed for radiations of wave length $\lambda = 1.05\mu$.

At room temperatures the natural crystalline material differs from other photoelectrically sensitive substances studied, in that the photoelectric response becomes fatigued and after an exposure of 2 to 3 seconds to light, the positive resistance change begins to be effective. On removing the light stimulus, the galvanometer gives a negative deflection, which in the course of a few minutes returns to the original zero scale reading. In other words, the change in resistance of the crystal when exposed to radiation is first negative, then positive, the resultant change being negative and roughly one-fourth the original change. At low temperatures, $-158°$ C., this polarization phenomenon disappears, and the response to radiation is the same as that of other substances, *e.g.*, selenium. The spectral photoelectric sensitivity curve of crystalline silver sulphide, acanthite, at room temperature is conspicuous for its high sensitivity in the region of the spectrum, extending from $0.6\mu$ to $1.2\mu$, followed by a maximum at about $1.35\mu$. Lowering the temperature to $-158°$ C. greatly increases the photoelectrical sensitivity of acanthite and produces a quite symmetrical curve with a maximum at $1.2\mu$.

Increasing the intensity of the exciting radiations shifts the maximum of the photoelectrical sensitivity curve toward the long wave lengths.

There is no simple law governing the variation in the photoelectric response in silver sulphide with variation in intensity of the radiation stimulus.

Mechanical working (hammering into a thin plate) appears to lower the intrinsic photoelectrical sensitivity of acanthite and changes the position of the maximum of spectral sensitivity.

A spectral photoelectric sensitivity curve of bismuthinite, $Bi_2S_3$, was obtained at $-166°$ C. There are maxima of sensitivity at $0.64\mu$, and $1.08\mu$, respectively.

# NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

## THE COMPOSITION AND BAKING VALUE OF THE DIFFERENT SIZED PARTICLES OF FLOUR.[1]

By J. A. LeClerc, H. L. Wessling, L. H. Bailey, and W. O. Gordon.

[ABSTRACT.]

AN investigation was conducted with 14 samples of flour to determine the composition and baking value of the different sized particles. Almost one-fourth of the flour, all of which was passed through a series of bolting silks number 15, 18, 20 and 21, remained on the No. 15 XX silk, while one-third passed through the No. 21. Upon analyzing and baking each separate, it was found that the quality of the coarse and very fine separates is inferior to that of the intermediate portion. The very fine separate is by far the poorest, both in quantity and quality of the gluten, as well as in the quality of the bread it produces. A superior quality of bread was secured when only the intermediate separates were selected for the baking.

## THE CRYSTALLOGRAPHY OF MORPHINE AND CERTAIN OF ITS DERIVATIVES.[2]

By Edgar T. Wherry and Elias Yanovsky.

[ABSTRACT.]

DETAILED crystallographic measurements and partial optical observations have been made on morphine monohydrate, codeine (morphine methyl ester), in both anhydrous and monohydrate forms, codethyline (morphine ethyl ester), monohydrate, and heroine (diacetyl morphine), anhydrous. All crystallize in the rhombic system, and on calculating the topic axes it is found that there are definite relations between them, it being possible to

* Communicated by the Chief of the Bureau.

[1] Published in the *Operative Miller*, vol. xxiv, No. 8, August, 1919.

[2] Published in *J. Washington Acad. Sci.*, vol. ix, No. 16.

recognize the direction in the crystal in which addition of the $CH_2$ group, the $H_2O$ of crystallization, and the acetyl groups takes place. The substances are too soluble in the liquids ordinarily used for the study of optical properties by the immersion method to permit accurate determinations of their refractive indices to be made.

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**Producer Gas for Internal Combustion Engines.**—The shortage of gasoline in Great Britain during the war led to extensive investigations for substitutes, among which were ordinary illuminating gas and producer gas. A report has just been published by the committee appointed to investigate the subject, an abstract of which is given in the *English Mechanic* (vol. cx, p. 31, 1919). The committee considers that gas traction is as safe as the ordinary form even when unprotected and exposed flexible containers are used. In its newer forms it is well worth consideration as an alternative of electric, gasoline or steam traction. Common city gas is estimated to be equivalent to gasoline in the proportion of 250 cubic feet of the former to 1 gallon of the latter. Presumably, these being English data, the city gas is more largely hydrocarbons than much of the gas supplied to American cities, and the gallon may be the imperial gallon of ten avoirdupois pounds. It is recommended, however, that gas-bags should be replaced by rigid or semi-rigid containers, whenever a compression plant can be installed, but it is not considered advisable that any existing plant for gas-traction should be abandoned at this time. Figures on cost of compressing, etc., are given, but they are obviously of no value in this country.

In a supplementary article (E. M., same volume, page 45) Mr. David J. Smith, who made many of the experiments in the matter, states that it is possible to run satisfactorily in competition with gasoline motor vehicles by producing gas made on the vehicle, using anthracite, coke or charcoal. He states that the cost of running a truck with anthracite at 50 shillings ($11) per ton was equivalent to gasoline at 5.4 pence (11 cents) per gallon, the commercial rate of the gasoline being taken at 2s.6d. (about 60 cents) per gallon. He claims that a producer can be made according to his designs that will occupy no loading room on the truck, and free access to the equipment is secured. In case of trucks the weight of the equipment for producing the gas does not exceed 2 per cent. of the weight of the loaded vehicle. The method is applicable to boats and tractors, the small size of the plant rendering it suitable for applications to which formerly producer gas apparatus could not be applied.

H. L.

## NOTES FROM THE U. S. BUREAU OF MINES*

*Aluminum Oxidation.*—The oxidation of aluminum is being studied at the Pittsburgh station. A sample of aluminum powder was analyzed for oxide by all the methods that are in use, for the purpose of comparing and perfecting them. Comparative figures were obtained for the oxygen content of an aluminum sample as determined by the sodium hydroxide and iodine methods. The latter shows consistently a much higher oxide value than the former, and both methods show a steady decrease in the amount of oxide with increase in the time of contact between the reagent and the sample. Further work is in progress.

*Neumann Bands.*—Tests for the Neumann Band Committee of the National Research Council have progressed at the Explosives Experiment Station under the direction of S. P. Howell, a member of that committee, and four tests in triplicate were made on steel disks prepared from cold rolled steel shafting, carbon less than 0.15. Each set of disks was distorted by explosion of explosives in contact with them, the explosives having rates of detonation of 5716, 4470, 3190 and 1523 metres per second. These disks will be microscopically examined by Mr. F. B. Foley, of the Bureau of Mines, also a member of this Committee, now at Bedford Hills, New York. The object of the investigation is to determine what effect the velocity of deformation or rupture of steel has upon the number or character of Neumann bands produced in the steel.

*Lead Density.*—It appears that the density of lead is decreased materially when distorted quickly, as by an explosion, as shown by recent tests made at the Explosives Experiment Station of the Bureau of Mines, under the direction of S. P. Howell. When small lead cylinders having an average density of 11.403 were distorted by an explosive having a rate of detonation of 3341 metres per second, its density was reduced to 10.996, and when distorted by an explosive whose rate of detonation was 3035 metres per second, the density was reduced from 11.376 to 11.156, and when the rate of detonation of the explosive was

* Communicated by the Director.

2835 metres per second, the density of the lead was reduced from 11.383 to 11.228. It is believed, that this reduction in density is concomitant to the formation of minute voids in the lead, and further investigation is required to determine this. This confirms tests made in the winter 1888–1889 at the Massachusetts Institute of Technology by Robert C. Williams and J. C. Seager, and reported by Frederick W. Clark in the *Transactions of the American Institute of Mining Engineers*, vol. xviii, pp. 526, 527, in which the specific gravity of lead cylinders before firing was 11.51 and after firing a charge of explosive in the borehole in the lead cylinder, the specific gravity was 11.268.

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**Production of Ammonia by Synthesis.**—The economic production of ammonia from nitrogen and hydrogen directly will be a valuable addition to chemical industries. The Haber-Le Rossignol process has been brought to a high degree of perfection, and it is claimed that Germany relied almost entirely on it for the supply of nitrogen compounds during the war. American chemists have given considerable attention to it also. Briner and Baerfuss, in a lengthy paper in *Jour. d. Chim. Phys.* (vol. xvii, p. 71, 1919), give results of experiments on the union of nitrogen and hydrogen under the influence of the electric arc, the gases being under diminished pressure. They summarize the results as follows:

At pressures of not over 150 mm. of mercury, the arc assumes a sheath form, the length being, of course, dependent on the current strength and the pressure. This form has a powerful influence on the determination of the synthesis. Changes of pressure and of the metal used for electrodes affect the output of ammonia. The experimenters believe that the combination takes place because the molecules of the two gases are dissociated into the constituent atoms in the region of the arc. The reduced pressure favors this action and, therefore, contributes materially to the production of ammonia. The dissociation may be due to the heat alone, or result from more complex conditions. The condition described by Strutt, *Proc. Roy. Soc.* (vol. lxxxv, p. 219, 1911, *et seq.*), namely, the formation of allotropic nitrogen of high activity, was not observed in these experiments. The best results should theoretically be obtained by the use of a mixture of the elements in the proportion in which they exist in the compound, *i.e.*, N to $H_3$, but as both elements are not equally activated by the arc, it is likely that in practice an excess of nitrogen should be present as this is less activated than hydrogen.

H. L.

# THE FRANKLIN INSTITUTE.

## COMMITTEE ON SCIENCE AND THE ARTS.

*(Abstract of Proceedings of the Stated Meeting held Wednesday, September 3, 1919.)*

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 3, 1919.

MR. BENJAMIN FRANKLIN *in the Chair.*

The following report was presented for final action:

No. 2729: Simplex Fluid Meter. Action deferred.

R. B. OWENS,
*Secretary.*

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## MEMBERSHIP NOTES.

### ELECTIONS TO MEMBERSHIP.

*(Stated Meeting, Board of Managers, September 10, 1919.)*

RESIDENT.

MR. JOSEPH A. DOANE, Chemist, The Pennsylvania Salt Manufacturing Company, and for mail, 1243 Sedgley Avenue, Philadelphia, Pennsylvania.

MR. GUY D. FERNANDEZ, Electrical Engineer, 217 Atlantic Avenue, Camden, New Jersey, and for mail, Haddon Heights, New Jersey.

MR. HOWARD S. GRAHAM, Banker, 435 Chestnut Street, and for mail, 205 West Chestnut Avenue, Chestnut Hill, Philadelphia, Pennsylvania.

MR. H. CONRAD MEYER, Vice-President, Foote Mineral Company, 107 North 19th Street, and for mail, 70 East Penn Street, Germantown, Philadelphia, Pennsylvania.

MR. WILLIAM TIDDY Chief Chemist, Rainey-Wood Coke Company, Swedeland, Pennsylvania.

NON-RESIDENT.

MR. A. COLLY, P. O. Box 3583, Johannesburg, Transvaal, South Africa.

LIEUTENANT CONRAD V. HAHN, Ordnance Department, U. S. A., Aberdeen Proving Ground, Maryland, and for mail, 3526 Filbert Street, Philadelphia, Pennsylvania.

MR. CHARLES EUGENE RILLIÉT, Teacher, Polytechnic High School, 509 West 1st Street, Santa Ana, California, and for mail, 4223 Brighton Avenue, Los Angeles, California.

MR. CHARLES B. SANDS, Investment Securities, 932 Chestnut Street, Philadelphia, and for mail, P. O. Box 42, Ocean City, New Jersey.

MR. FRANK W. SUTTON, Industrial Engineer, 218 Engineers' Building, Cleveland, Ohio.

MR. CHRISTOPHER VAN DEVENTER, Consulting Engineer, 438 First National Bank Building, Chicago, Illinois.

MR. LUCIEN I. YEOMANS, Industrial Engineer, 72 West Adams Street, Chicago, Illinois.

ASSOCIATE.

MR. CARL T. MACK, Electrical Engineer, H. L. Doherty Company, 60 Wall Street, New York City, New York.

MR. SYLVAN D. ROLLÉ, Draftsman, Bell Telephone Company of Pennsylvania, and for mail, 2237 North 21st Street, Philadelphia, Pennsylvania.

## LIBRARY NOTES.

### PURCHASES.

American Society of Heating and Ventilating Engineers. Transactions, vol. xxiv. 1918.

BACKER, H. J.—Oude chemische Werktuigen en Laboratoria van Zosimos tot Boerhaave. 1918.

Cumulative Book Index, vol. xxi. 1919.

HUBBARD, E.—The Utilization of Wood Waste. 1915.

PAUL, J. H.—Boiler Chemistry and Feed Water Supplies. 1919.

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Allis-Chalmers Manufacturing Company, Illustrated Catalogue No. 107. Milwaukee, Wisconsin, 1919. (From the Company.)

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American Petroleum Products Company, Booklet, "The Use of Oil as a Fuel." Cleveland, Ohio, 1919. (From the Company.)

American Well Works, Catalogue No. 149. Aurora, Illinois, 1917. (From the Works.)

Atlas Car and Manufacturing Company, Bulletin No. 1185. Cleveland, Ohio, no date. (From the Company.)

Australia Geological Survey, Bulletins Nos. 67 to 76, inclusive. Perth, 1916–1917. (From the Government Geologist.)

Barrett Company, Booklet on the Methods of Analysis of the Coal-Tar Industry. New York City, New York, 1918. (From the Company.)

British Association for the Advancement of Science, Report, 1918. London, 1919. (From the Association.)

Burt Manufacturing Company, The Burt Booklet. Akron, Ohio, 1917. (From the Company.)

Canada Department of Mines, Memoirs 107, 108, 110 and 113. Ottawa, Canada, 1919. (From the Department.)

Carnegie Institute of Technology, General Information for 1919–1920. Pittsburgh, Pennsylvania, 1919. (From the Institute.)

Commercial Truck Company of America, Bulletin No. 15. Philadelphia, Pennsylvania, 1919. (From the Company.)

Connecticut Public Utilities Commission, Seventh Annual Report for 1918. Hartford, 1919. (From the Commissioner.)

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Cutler-Hammer Manufacturing Company, Publications Nos. 413 and 445. Milwaukee, Wisconsin, 1919. (From the Company.)

DePere Manufacturing Company, Bulletins Nos. 1 to 7, inclusive. Chicago, Illinois, 1918–1919. (From the Company.)

Electric Service Supplies Company, Catalogue of Flood Lighting Projectors. No date. (From the Company.)

Elliott Company, Combined Catalogue. Pittsburgh, Pennsylvania, 1919. (From the Company.)

Engineer Company, Catalogue, "The Development of an Idea." New York City, New York, no date. (From the Company.)

Falls River Company, Catalogue No. 19. Kent, Ohio, 1919. (From the Company.)

Foundry Equipment Company, Booklet, Coleman Ovens for Cores and Molds. Cleveland, Ohio, 1919. (From the Company.)

Hobart College, Catalogue, 1918–1919. Geneva, New York, 1919. (From the College.)

Horton E., & Son Company, Catalogue No. 16. Windsor Locks, Connecticut, no date. (From the Company.)

Hydraulic Press Manufacturing Company, Catalogues Nos. 43 and 80. Mount Gilead, Ohio, 1919. (From the Company.)

Illinois Electric Porcelain Company, Catalogue of Electrical Porcelain Insulations. Macomb, Illinois, no date. (From the Company.)

Iowa Railroad Commission, Fortieth Annual Report for the year ending December 3, 1917. Des Moines, 1919. (From the Commissioners.)

Iowa State College of Agriculture and Mechanic Arts, General Catalogue, 1919–1920. Ames, Iowa, 1919. (From the College.)

Jaeger Machine Company, Catalogues of Concrete Mixers. Columbus, Ohio, no date. (From the Company.)

Jewell Electrical Instrument Company, Catalogue No. 12. Chicago, Illinois, no date. (From the Company.)

Kungl. Vitterhets Historie och Antikvitets Akademien, Antikvarisk Tidskrift for Sverige. Stockholm, Sweden, 1919. (From the Academy.)

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Locomotive Stoker Company, Publication No. 15. Pittsburgh, Pennsylvania, 1916. (From the Company.)

McKiernan-Terry Drill Company, Bulletins Nos. 25 and 26. New York City, New York, 1919. (From the Company.)
Mason Regulator Company, General Catalogue No. 60. Boston, Massachusetts, 1919. (From the Company.)
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Merchant & Evans Company, Catalogue of Almetl Fire Doors and Shutters. Philadelphia, Pennsylvania, 1918. (From the Company.)
Mercury Manufacturing Company, Publication, "The Trackless Train." Chicago, Illinois, no date. (From the Company.)
Metal Forms Corporation, Catalogue of Metaform Outfits. Milwaukee, Wisconsin, no date. (From the Corporation.)
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New Hampshire Public Service Commission, Annual and Statistical Report, 1917. Manchester, New Hampshire. (From the Commission.)
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Oliver Continuous Filter Company, Bulletin No. 12 of the Oliver Filters. San Francisco, California, 1919. (From the Company.)
Packard Electric Company, Bulletin No. 201. Warren, Ohio, 1919. (From the Company.)
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Pennsylvania Legislative Reference Bureau, Bulletin No. 19. Harrisburg, Pennsylvania, 1918. (From the State Librarian.)
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Pittsburgh Iron and Steel Foundries Company, Catalogue of Adamite. Pittsburgh, Pennsylvania, 1917. (From the Company.)
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Schramm, Chris D. & Son, Inc., General Catalogue No. 18. Philadelphia, Pennsylvania, no date. (From Chris D. Schramm & Son, Inc.)

Seneca Falls Manufacturing Company, Inc., Catalogue No. 27, Seneca Falls, New York, no date. (From the Company.)

Smith Engineering Works, Bulletins Nos. 261 and 266. Milwaukee, Wisconsin, no date. (From the Works.)

Southern Pacific Company, Thirty-fifth Annual Report for 1918. New York City, New York, 1919. (From the Company.)

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Tempe Normal School, Bulletin No. 1. Tempe, Arizona, 1919. (From the School.)

Temple University, Annual Catalogue, 1919. Philadelphia, Pennsylvania, 1919. (From the University.)

Thew Automatic Shovel Company, Industry Bulletins Nos. 28 to 30, inclusive. Lorain, Ohio, no date. (From the Company.)

Trane Company, Catalogues of Texaco at Home and Abroad. Houston, Texas, 1917. (From the Company.)

United Engineering and Foundry Company, Bulletin No. 1. Pittsburgh, Pennsylvania, 1919. (From the Company.)

United States National Association of State Universities, Transactions and Proceedings for 1918. Lexington, Kentucky, 1919. (From the Association.)

United States Shipping Board Emergency Fleet Corporation, Report on the Work of the Training of Shipyard Workers. Philadelphia, Pennsylvania, 1919. (From the Corporation.)

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University of Montana, Nineteenth Annual Catalogue for 1918–1919. Butte, 1919. (From the University.)

U. S. Light and Heat Corporation, Bulletin No. 700. Niagara Falls, New York, 1919. (From the Corporation.)

Valley Iron Works Company, Catalogue of the Vesuvius Sulphur Burner. Appleton, Wisconsin, 1916. (From the Company.)

Van Dorn Electric Tool Company, Catalogue No. 19. Cleveland, Ohio, no date. (From the Company.)

Weber Chimney Company, Catalogue No. 19. Chicago, Illinois, no date. (From the Company.)

Westinghouse Electric and Manufacturing Company, Catalogue of Electric Arc Welding. East Pittsburgh, Pennsylvania, no date. (From the Company.)

Wilmot Engineering Company, Catalogue of Breaker Machinery. Hazleton, Pennsylvania, no date. (From the Company.)

## BOOK NOTICES.

HYGIENE IN MEXICO: A STUDY OF SANITARY AND EDUCATIONAL PROBLEMS. By Alberto J. Pani, C.E. Translated by Ernest L. de Gogorza. 206 pages, and contents, 12mo. New York, G. P. Putnam's Sons. Presented by the author.

General public hygiene is rather out of the scope of this JOURNAL, but it is a subject growing more and more closely related to engineering and chemistry, and besides, American interest in Mexico is so great that it will be worth while to examine the work of one who has had a large experience in the field. Senor Pani is an officer of the Carranza government and informs us in a special note that the sole purpose of the book is "to expose one of the least known, most nefarious and shameful inheritances of the past." This refers to the oppressions of the Diaz government. The entire proceeds of the sale of the Spanish edition were donated to the People's University of Mexico, which institution is especially organized to promote education among the less cultured classes of the nation.

The work is, of course, largely statistical. It gives evidence of great neglect of hygiene among the mass of the Mexican population. His investigations lead him to the opinion, expressed on page 7, that Mexico City is the most unhealthful city in the world. Some very interesting figures of the earnings and living expenses of the laborers in the city are given. One receives seventy-five cents a day (presumably U. S. money equivalent) working every day. He supports two others—mother and wife. His food costs per week, $3.62; clothing, washing and hair cutting, $.94; room rent (very squalid quarters), $.50; leaving a weekly surplus of $.19.

The book is a valuable contribution to general hygiene. Those who desire to know something of the "Mexican problem" should consult it. The work of the translator is very well done. The English is excellent, free from Spanish idioms.

HENRY LEFFMANN.

## PUBLICATIONS RECEIVED.

*Traité de Mécanique Rationelle*, par Paul Appell. 4me edition, entierement refondue. Tome premier, statique-dynamique du point. 619 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie, 1919. Price, 36 francs.

*Ontario Bureau of Mines:* Report, 1918, Sand and Gravel in Ontario, by A. Ledoux. 138 pages, illustrations, maps, 8vo. Toronto, King's Printer, 1918. Abitibi-Night Hawk Gold Area, by C. W. Knight, A. G. Burrows, P. E. Hopkins and A. L. Parsons. Larder Lake Gold Area, by P. E. Hopkins. 84 pages, illustrations, plates, maps, 8vo. Toronto, King's Printer, 1919.

*U. S. Bureau of Mines:* Bulletin 150, Electrodeposition of Gold and Silver from Cyanide Solutions, by S. P. Christy. 171 pages, illustrations, plates, 8vo. Washington, Government Printing Office, 1919.

*University of Missouri School of Mines and Metallurgy:* Bulletin, August, 1919. The Carbonization of Missouri Cannel Coals, by Howard Leroy Dunlap, assisted by Karl Kenneth Kershner and Vivian Xly Smiley. 52 pages, illustrations, 8vo. Rolla University, 1919.

# CURRENT TOPICS

**Production of Glycerin from Sugar by Fermentation.**—JOHN R. COFF, W. V. LINDER and G. F. BEYER (*Journal of Industrial and Engineering Chemistry*, vol. xi, pp. 842–845, 1919) have studied the production of glycerin from sugar by fermentation with yeast. Several successive sowings of the Steinberg variety of *Saccharomyces Ellipsoideus* are made, each sowing while the yeast is most active. Sodium carbonate is added at each sowing so that its concentration is from one-half to one per cent. of the weight of the nutrient solution; the yeast is thereby accustomed to an alkaline environment. The yield of glycerin is greater in an alkaline solution than in either a neutral or an acid solution. The yeast culture is added to a sugar solution, *e.g.*, a solution of black strap molasses; the most favorable concentration is from 17.5 to 20.0 grains of sugar per 100 c.c. of solution. The fermentation is carried out at a temperature of 30° to 32° C. in the presence of a small amount of ammonium chloride. Solid sodium carbonate is added to the wash from time to time; when a sufficient quantity has been added, a copious precipitate forms, evolution of gas ceases, and the yeast apparently lies dormant for a time, the precipitate eventually disappears and fermentation again occurs. The formation of a precipitate and the quiescence of the mash are essentials of the process. The best results are obtained when the total amount of sodium carbonate added is approximately 5 per cent. The entire amount cannot be added at one time, for it would permanently stop the fermentation; on the other hand, the yield of glycerin is greater the earlier the entire amount has been added in several installments with intervening cycles of precipitation, quiescent period, and fermentation. The requisite alkalinity of the medium may also be obtained by use of potassium carbonate, sodium hydroxide, potassium hydroxide or borax. When fermentation is completed, from 20 to 25 per cent. of the sugar has been converted into glycerin, the remainder into carbon dioxide and alcohol; other products, as yet unidentified are formed in small amount. The alcohol may be recovered by distillation. The glycerin is obtained by neutralizing the fermented solution with sulphuric acid, purifying by addition of coppers and lime, removing the precipitate in a filter press, concentrating the filtrate in a vacuum evaporator, and finally distilling in a suitable still. On a commercial scale, corn sugar and cane sugar were less satisfactory than molasses as a raw material. Their solutions had to be enriched with yeast nutriate of such a nature and to such an extent that these nutrients interfered with the purification of the glycerin.

J. S. H.

**Potash Recovery in Cement Works.**—The discovery that a limited amount of soluble alkalies exists in the dust of cement plants seems to be due to Seger and Cremer, who in 1904 reported on the fact in *Thonind.-Zeit.* abstracted in *Jour. Soc. Chem. Ind.* (vol. xxiii, p. 531, 1904). The possibility of recovering this alkaline material was first pointed out by Clifford Richardson at a meeting of the American Society for Testing Materials in June, 1904. At this time Richardson stated that in a cement plant turning out 4000 barrels per day there might be a possible profit of between $100 and $200 per day. This was, of course, at the prices then ruling for potassium salts.

The data just given are taken from a report by the Department of Mines of Canada, bulletin 29, prepared by Alfred W. G. Wilson, Ph.D., Special Investigator for the War Trade Board. A considerable amount of information is given as to the results of recovery of potassium salts from the dust of the cement works, principally in the United States. Several illustrations are included, all of which are United States installations. It is also stated that potassium salts may be recovered from blast-furnace gases, and that three steel plants in the United States are experimenting on this matter, and further that in Great Britain it is believed that the yield from this source will suffice for domestic wants.

Two systems are in vogue for recovery from cement dust, the electrical precipitation under the Cottrell patents and the water spray system. A double benefit results from these methods, for not only is a valuable fertilizer obtained, of which there is a shortage in America, but a very objectionable dust is condensed. In fact, in one case it was due to legal proceedings against the works that the dust remover was installed and as a secondary result the potash yield was obtained and for a limited time, owing to the high price of potash salts, the by-product was the most profitable output of the plant.

The bulletin concludes with the advice that the problem of by-product recovery should receive the attention of all Canadian cement manufacturers. Of course, this advice will be worth considering by United States manufacturers as well. Not the least advantage will be removal of annoyance to the neighborhood by the escaping dust, especially objectionable in agriculture districts, and also very injurious to the workers in the plants. Thus we have the fortunate combination of industrial hygiene and increase of operation profit to bring about material improvement in such plants. H. L.

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## ATMOSPHERIC ELECTRICITY.*

BY

W. F. G. SWANN, A.R.C.S., D.Sc.,

Professor of Physics at the University of Minnesota.[1]

### INTRODUCTION.

It had been surmised by several early investigators that lightning and the electric discharge were in some way connected; but, it was not until the middle of the eighteenth century that Franklin, the pioneer whose name this institution bears, showed, by obtaining electrical discharges from a kite, that there was really a very close connection between the two phenomena.

Although the electrical manifestations of the atmosphere attain their most spectacular form in the thunderstorm, nevertheless, during the ordinary quiet days, our air is constantly the seat of electrical phenomena hardly less interesting and puzzling to the student of science.

Our earth is not an electrically neutral body. Its surface is coated with a charge of negative electricity; and the amount of this charge is such as to give rise to a very considerable electrical field in the atmosphere. In the technical mode of expression we say that the potential increases, as we rise above the earth's surface, to the extent of about 150 volts per metre; that is to say, the

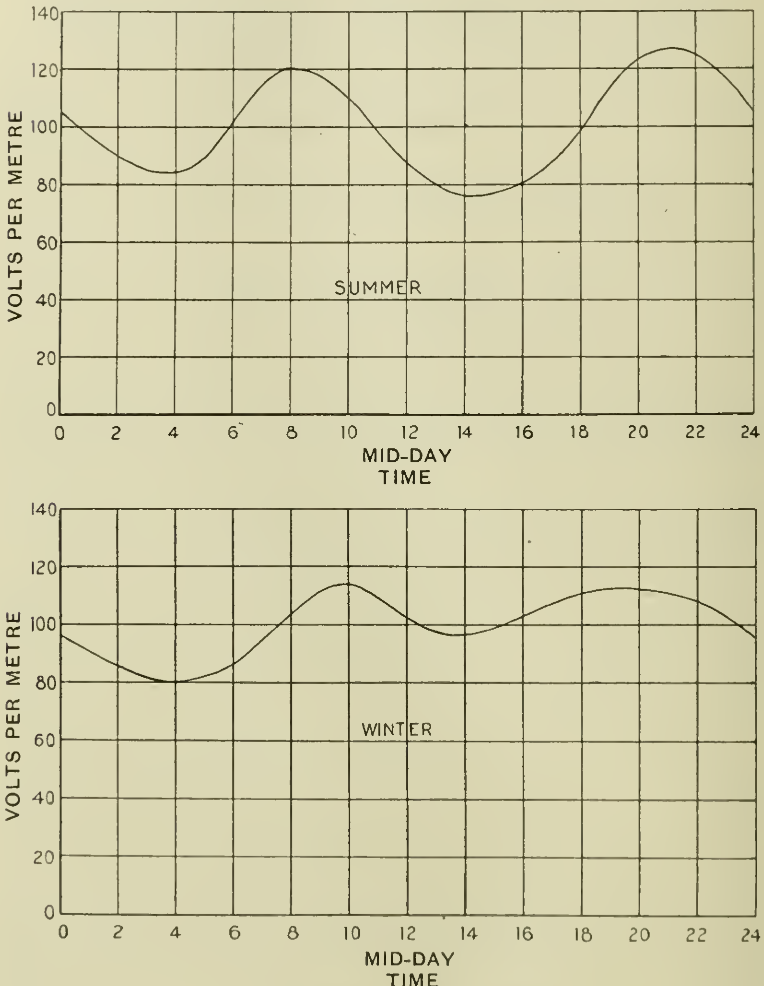
* Presented at a joint meeting of the Electrical Section and the Philadelphia Section American Institute of Electrical Engineers, held Thursday, November 1, 1917.

[1] At the time this lecture was given, Chief of the Physical Division, Department of Terrestrial Magnetism, Carnegie Institution of Washington.

[Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.]

difference in electrical pressure between the earth and a point one metre above its surface is about one and a half times as great as the difference in electrical pressure between the terminals of

FIG. 1.

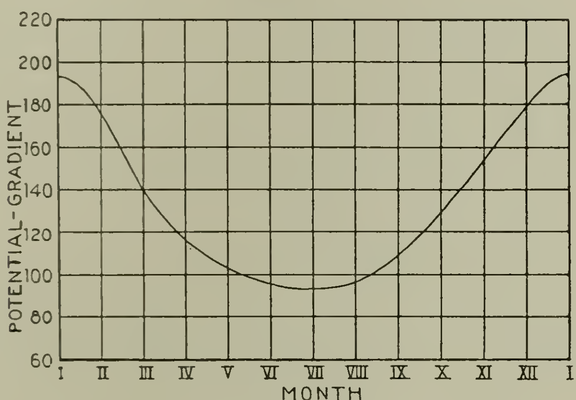



Diurnal variation of potential-gradient

our lighting circuits. The change of electrical potential per metre is called the potential-gradient, and is one of the atmospheric-electric quantities most frequently studied.

Except in abnormal weather, the potential-gradient is almost invariably directed in such a way as would result in negative electricity being repelled away from the surface of the earth; that is, in such a way as to correspond to the existence of a negative charge upon the earth's surface. It is by no means an invariable quantity, however, but goes through a fairly regular series of changes throughout the day, and throughout the year, changes amounting to fifty per cent. or more of its whole value. In Fig. 1 the upper curve is typical of the variation of the potential-gradient throughout the day in summer, and the lower curve is typical for a winter day. If we take the average value of the potential-gradient for each day of the year, and plot this quantity through-

FIG. 2.




out the year, we obtain such a curve as Fig. 2, showing that the potential-gradient is high in winter and low in summer.

The change in electrical potential in the second metre above the earth's surface is slightly less than for the first; for the third metre it is slightly less than for the second, and so on. This diminution of the potential-gradient with altitude has been traced by balloon observations up to altitudes of nine kilometres, where the potential-gradient attains a value of only about 2 volts per metre instead of 150 volts per metre, which is the value at the earth's surface. It does not require a great stretch of the imagination to suppose that if we could go still higher, the gradient would soon attain a practically negligible value.

Now nine kilometres is so small compared with the radius of

the earth that if we were to represent the earth by a circle drawn upon an ordinary page, we should find difficulty in drawing the circle with a line so thin but that its thickness alone would represent more than nine kilometres. We realize how much remains to be known on the purely experimental side of atmospheric-electricity when we recall that practically all of our measurements are confined to a very thin shell of this kind, and indeed, most of them to a very small fraction of this shell. If we could only know something of the conditions over a shell thirty or forty kilometres thick, we should probably be on the high road to the solution of much that is now obscure.

I have said that, within a thin shell of the atmosphere only about ten kilometres thick, the potential-gradient falls from about 150 volts per metre to practically zero. It can be shown as a matter of pure mathematical reasoning from the known laws of electrostatics that the only explanation of this diminution of potential-gradient with altitude is to be found in the supposition that the portion of the atmosphere within the shell holds a positive charge just equal to the negative charge on the surface of the earth; and direct experiment has, of course, confirmed the presence of this positive charge.

Now a state of affairs where a negative charge is to be found on the surface of the earth and a positive charge in the surrounding atmosphere is one which could persist indefinitely if the atmosphere were a perfect insulator. But it is not a perfect insulator. Its power of conducting electricity is extremely small; but, it is nevertheless sufficient to insure that 90 per cent. of the charge on the earth's surface would disappear in about 10 minutes if there were no means of replenishing the supply. The origin of the replenishment of the earth's charge, which we shall presently discuss in greater detail, has for long been the most puzzling problem of atmospheric electricity.

### ATMOSPHERIC CONDUCTIVITY.

As I have remarked, the conductivity of the atmosphere is very small. Compared with the conductivity of such a substance as copper, it is almost inconceivably small. A column of air one inch long offers as much resistance to the passage of the electric current as a copper cable thirty thousand million million miles long, and of the same cross-section, *i.e.*, as much resistance

as that of a copper cable long enough to reach from here to Acturus and back twenty times. In view of the very small conducting power of the atmosphere, we might be constrained to imagine that the difficulty is not to explain that conductivity, but rather to explain why the conductivity is not much greater than it actually is. Nevertheless, modern work on the origin of electrical conduction in gases has lead to such definite conceptions of the mechanism of this process that even the conductivity of the atmosphere is not so small as to avoid the necessity of an explanation of its origin.

According to modern views, matter is composed almost, if not entirely, of positive and negative particles or electrons. We know a great deal about the negative electrons. They all carry the same electric charge, and are all of the same size and mass, the radius being about $10^{-13}$ cm. and the mass about $10^{-27}$ gramme. The ordinary molecule of oxygen or nitrogen contains as much positive as negative electricity; and, if placed in an electric field, it would show no tendency to move. As a result of certain agencies, however, it is possible to detach a negative electron from a molecule, leaving the remainder positively charged. This remainder constitutes what is called the positive ion. The negative electron may travel freely for some time, but sooner or later it will attach itself to a neutral molecule, or, according to the views of some, to a group of molecules, and so form the negative ion. These ions render the air conducting because, under the influence of an electric field, the negatively and positively charged ions move respectively towards the positively and negatively charged bodies and discharge them.

Now suppose that, in the atmosphere, there is some agency which produces ions continually. The number of ions per c.c. will grow and grow; it would grow indefinitely were it not that the ions which have been produced tend to recombine, positive to negative, by their mutual attraction; and, the more there are present, the more rapidly do they recombine. If the ions are produced at a constant rate, the number per c.c. will grow only until the number which recombine per second is equal to the number produced per second. Thus, to take a concrete example, it appears that, in the atmosphere, about 6 pairs of ions are produced per cubic centimetre each second; and, by the time the number has grown to about 2400 of each kind per c.c., six pairs of ions

will recombine per second, and the total number will cease to grow further.[2]

How, then, are we to account for the constant production of ions in the atmosphere? It appears that, in the lower temperature, two causes are mainly responsible:

(1) The radioactive emanations in the air.

(2) The "penetrating radiation."

Concerning the former, I must first remind you that, according to modern views, a substance like radium is in a continual state of disintegration. The disintegration of radium itself takes place very slowly; about 2000 years must elapse before a given quantity of radium becomes reduced to one-half of its original amount. As the radium decays, it gives birth to a gas called radium emanation. This gas is much shorter lived than radium itself. Half of any given quantity of it disappears in 3.85 days; and as it dies it gives birth to another substance, radium $A$, which again dies, giving rise to radium $B$ and so on.

Now the study of the radioactive substances has shown that when one of these atoms disintegrates and gives rise to the next in succession, one or all of three types of radiation are emitted from the atom. First, there is the $\alpha$ particle, a positively charged atom of helium, having a mass equal to four times that of the hydrogen atom, and travelling with a velocity of the order one-tenth that of light, which itself travels with a speed of 186,000 miles per second. Then there is the $\beta$ particle which is merely an ordinary negative electron, travelling with a velocity comparable with that of light, and having a mass one two-thousandth that of the hydrogen atom. Lastly, there is a type of radiation, the $\gamma$ radiation, which is generally supposed to be some sort

[2] At this point the lecture was illustrated by an experiment. An insulated conducting cylinder was shielded by an earthed metal cylinder, and connected by means of a wire to a quadrant by a DoleZalek electrometer, whose other quadrant was connected to the electrometer case, which was mounted on an insulating support. From the electrometer mirror a spot of light was reflected to a scale on the screen. By means of a fan a current of air could be drawn through the space between the two cylinders. A battery of 150 volts maintained a difference of potential between the two cylinders, so that if ions were drawn into this region by the fan, those of appropriate sign were driven across to the central cylinder and so caused a deflection of the spot of light.

By means of this apparatus, the ions introduced into the air entering the cylinders, by means of a match flame, and a tube of radium held over the open end were made evident.

of an ether pulse, but not primarily of as material a nature as the $\alpha$ or $\beta$ particle.

Now all of these radiations possess the power of ionizing, either directly or indirectly, a gas through which they pass. The $\alpha$ particles are very efficient ionizers; and, so busily do they set about their work, that they expend all their available energy in this process and come to rest in passing through only a few centimetres of air. The $\beta$ particles are much less efficient ionizers. They pass through the gas with but little commotion, and may travel several metres before coming to rest. The $\gamma$ rays are still more penetrating and less efficient ionizers than the $\beta$ particles; and their intensity still retains 36 per cent. of its initial value after they have passed through 100 metres of air.

Now the soil contains radium and other substances of this nature, and these give rise to active gaseous emanations which diffuse out into the atmosphere. During the disintegration of these emanations in the atmosphere, $\alpha$, $\beta$, and $\gamma$ rays are emitted with the result that the air becomes ionized and is rendered conducting. The amount of radium emanation in the atmosphere varies very much from time to time. It is, however, always extremely small. In a shell of the atmosphere extending over the whole of the earth's surface and comprised between that surface and an altitude of one kilometre, we shall find only about 250 grammes of radium emanation. Or, expressing this magnitude in another form, we may say that each cubic centimetre of the atmosphere contains on the average only between one and two molecules of radium emanation, as compared with the thirty million million million molecules of air which it holds. Nevertheless, by adding up the ionization produced by the $\alpha$, $\beta$, and $\gamma$ rays from the emanation and its products we are able to account for the production of 1.7 ions per second in each cubic centimetre of the atmosphere. In addition to radium emanation, another radioactive gas, thorium emanation, is also to be found in the atmosphere and contributes to the ionization. Again, a certain amount of atmospheric ionization is attributable to the radioactive materials in the soil. Here we are only concerned with the $\gamma$ ray ionization, since the $\alpha$ and $\beta$ rays are so readily absorbed that they never succeed in getting out of the soil. The soil contains, on an average, about $4 \times 10^{-12}$ gramme of radium per c.c., and, by calculating the amount of $\gamma$ radiation which can be

accounted for, after allowing for the absorption of the rays coming from different depths in the soil, we find enough to provide for the production of 0.80 ion per c.c. per second. In a similar way, the thorium in the soil is found to be capable of accounting for a rate of production of 0.80 ion per c.c. per second.

Table I.

*Ionization of the Atmosphere by Radioactive Material.*

| Type | Whence | Radium | Thorium | Total |
|---|---|---|---|---|
| $\alpha$ rays | Air | 1.63 | 1.00 | 2.63 |
| $\beta$ rays | Air | 0.035 | 0.025 | 0.06 |
| $\gamma$ rays | Air | 0.035 | 0.025 | 0·06 |
| $\gamma$ rays | Earth | 0.80 | 0.80 | 1.60 |
| | | 2.50 | 1.85 | 4.35 |

These results on the amount of ionization which the radioactive material is capable of accounting for are summarized in the accompanying table taken from a paper by A. S. Eve [3]; and it appears that, altogether, a rate of production of 4.35 ions per c.c. per second can be accounted for in this way. From a knowledge of the rate at which ions recombine we can calculate the number to which they would build up in the atmosphere on account of a rate of production of 4.35 ions per c.c. per second, and the result comes out to 1320 ions of each sign per c.c.

Measurements of the numbers of ions per c.c. in the atmosphere are attended with considerable difficulty, for all sorts of different types are present. In particular, there is a class of ion which is very sluggish in its motion, and which is probably nothing more than an ordinary ion which has attached itself to a dust particle. On account of their sluggishness, these ions contribute very little to the conductivity, but they nevertheless influence the requirements in the matter of rate of production of ions; for, they contribute to the rate at which the ions recombine. It has been customary to measure the numbers of ions per c.c. by a method which takes account of the most mobile ions only, and it appears that about 800 pairs of these exist per c.c. Thus, quite apart from the direct evidence of the existence of the sluggish ions, we may conclude that ions of this type must be present,

[3] "On the Ionization of the Atmosphere due to Radioactive Matter." *Phil. Mag.*, S. 6, vol. xxi, pp. 26–40, 1911.

since the radioacitve material in the air and soil is alone capable of accounting for 1320 ions per c.c.

The uncertainty of our knowledge of the true average values for the total numbers of ions of all kinds, and of the appropriate rates of recombination, prevents us from doing more than to say that, as far as measurements on land are concerned, the radioactive material in the air and earth is sufficient to account for the whole of the ionization produced. A difficulty presents itself, however, when we consider the results of observations made over the sea. Those who have made observations over the ocean have found very little radioactive material. Some of the most recent observations have been made on the yacht *Carnegie,* owned by the Carnegie Institute of Washington; and, as a result of observations extending over about 50,000 miles in the Pacific and Sub-Antarctic Oceans, an average radioactive content was found, for the atmosphere, amounting to only 2.5 per cent. of that found on land, and the radioactive content of the sea water collected in regions remote from land was immeasurably small. Nevertheless, the number of the more mobile ions found per c.c. over the ocean is as great or greater than that found over land, as will be seen from Table II, which represents a comparison of the results of the *Carnegie's* fourth cruise with those obtained by other observers at sea, and with land values. The number of ions is much larger than can be accounted for by the small quantity of radioactive material in the ocean air.

TABLE II.

*Comparison of Land and Sea Values of the Ionic Content.*

| Nature of observations | Number of positive ions per c.c. | Number of negative ions per c.c. |
|---|---|---|
| Mean of land observations obtained by various observers | 737 | 668 |
| Mean of ocean values for the fourth cruise of the *Carnegie* | 804 | 677 |
| Mean of former ocean values obtained by various observers | 736 | 588 |

What, then, is the agency responsible for the ionization over the ocean? It appears to be the so-called "penetrating radiation." If a hermetically sealed vessel is freed from radioactive air, we nevertheless find that ions are produced in it at a fairly

constant rate of about 10 ions per c.c. per second over the land. An appreciable proportion of this ionization is due to the $\gamma$ ray radiation which comes from the soil and passes through the walls of the vessel. That the whole of it is not due to this cause is, however, borne out by several circumstances. In the first place, ionization in closed vessels is found to take place over the ocean, where there is practically no radioactive material, and it there amounts to about 4 ions per c.c. per second in a copper or a zinc vessel. Secondly, if, in experiments on land, the apparatus is surrounded by a wall of water of sufficient thickness to shield off practically completely the $\gamma$ ray radiation from the earth, there still remains a rate of production of about 4 ions per c.c. per second. But the strongest evidence of the reality of the penetrating radiation is to be found in the results obtained in balloon ascents by W. Kolhörster.[4] It appears that, with increase of altitude, the ionization within a closed vessel at first diminishes up to an altitude of 700 metres. This we should expect as a result of the absorption of the earth's $\gamma$ ray radiation by the atmosphere. Above this altitude an astonishing thing happens, however. The ionization commences to increase, and goes on increasing with greater and greater rapidity until, at an altitude of 9000 metres, the intensity of ionization is in excess of that at the earth's surface by about 80 ions per c.c. per second. An increase of 20 ions per c.c. per second takes place in the last kilometre, and the rapidity of the increase at these higher altitudes is such as to suggest that very large values of the ionization would be obtained at altitudes not very much greater.

It thus appears that there is some source of ionization other than the radioactive materials in the soil and lower atmosphere; and this agency, whatever its origin, appears to be the sole source of ionization over the ocean. The rate of production of ions must certainly be greater over the land than over the ocean by the amount attributable to the radioactive materials on land. It is probable, however, that over the land, where dust nuclei are more plentiful than over the ocean, a much larger proportion of the ions produced join the slowly moving class than is the case with the ions produced over the ocean; and it is to this cause that we must attribute the fact that the ionic density for the more mobile ions is no greater over the land than over the sea.

[4] Aerophysikalischer Forschungsfonds Halle, Abhandlung 14.

To return to the remarkable increase with altitude shown by the ionization within closed vessels. Such a variation at once suggests a radiation coming from some source external to our globe, or from some active agency in the upper regions of the atmosphere, the decrease in intensity encountered as we *descend* into the atmosphere being accounted for by absorption. The rapidity of the absorption can be calculated from the observations on the variation of intensity with altitude; and, it appears that the observations require us to assume for the radiation a penetrating power ten times that of the most penetrating $\gamma$ rays known in radioactive substances. We must not be too greatly skeptical as to the possibility of the existence of so penetrating a radiation, for light itself is extremely penetrating as regards air, since we can see the stars through the whole thickness of our atmosphere. The "penetrating radiation" is not light, however, for it can pass through the walls of a metal vessel. Its true origin remains one of the most interesting speculations of atmospheric electricity. Linke has suggested a layer of strongly radioactive cosmical dust in the atmosphere at an altitude of 20 kilometres. For my own part, it seems more natural to seek an explanation from another stand-point.[5]

It is generally supposed that the Aurora is due to light generated by the impact, with our atmosphere, of negative electrons shot from the sun. The stream of electrons is not confined to the sunlit side of the earth, since the paths of the electrons are bent in passing through the earth's magnetic field, and some enter our atmosphere on the side remote from the sun. Now it is a well-established fact that when electrons strike molecules of matter $X$ rays are produced. The greater the velocity of the electrons, the higher the penetrating power of the $X$ rays produced. $\gamma$ rays themselves are nothing more than a particularly penetrating type of $X$ rays. Modern developments in our knowledge of $X$ rays and $\gamma$ rays have taught us how to calculate the velocity which an electron must have in order to produce $\gamma$ rays of any given degree of penetration. Now, from considerations of the theory of the Aurora, into which time will not permit me to enter, Birkeland has shown that it is necessary to assume that the electrons which are responsible for this phenomenon have an energy enormously

[5] The paragraph following this remark was not included in the lecture as given.

greater than that of even the swiftest $\beta$ rays with which we are familiar in the laboratory; and, if we invoke the assistance of these high-speed electrons necessitated by the theory of the Aurora, we find that their speed is sufficiently great to account for the production of a $\gamma$ ray radiation of a degree of penetration fully as great as that of the "penetrating radiation." The electrons themselves are not the "penetrating radiation" for, in spite of their great energy, they could not travel right through our atmosphere. By conversion of their energy into the $\gamma$ ray type, however, a radiation of much greater penetrating power is created.

### ATMOSPHERIC-ELECTRIC MEASUREMENTS.

Time will not permit an extensive discussion of atmospheric-electric measurements; but a general survey of this field may perhaps best be given by a very brief description of the procedure adopted on the *Carnegie's* fourth cruise, in respect of which it fell to my lot to plan the work and devise the instruments and methods of measurement.

The quantities measured were: The potential-gradient, the conductivities arising from the positive and negative ions, the numbers of positive and negative ions per cubic centimetre, the radioactive content of the atmosphere and of the sea water, the numbers of pairs of ions produced per c.c. per second in a hermetically sealed vessel, and the diurnal variations of the potential-gradient and ionic density. The ionic mobilities were calculated from the results for conductivity and ionic density, and, in addition, the pressure, temperature, and humidity were measured.

*Electroscopes.*—All the measurements require, at some stage of the operation, the use of an electroscope. It will be recalled that the ordinary type of electroscope consists of two gold leaves suspended on a rod which is fixed in an insulating plug, and surrounded by a metal case. This type is quite unsuitable for use at sea, on account of the disturbing influence of the motion of the ship. Within recent years, however, another type of electroscope has been devised, in which the controlling force is brought about by a method independent of gravity. In one form of the instrument, the bi-filar electroscope of Wulf, the gold leaves of the older electroscopes are replaced by two quartz fibres coated with platinum to render them conducting. At their upper ends, the fibres are soldered to the main terminal of the instrument, and

their lower ends are attached to a quartz bow whose ends are fixed to a frame. When the fibres are charged, they repel each other, and the resulting motion, which can be read by a microscope with a scale in the eye-piece, is resisted by the quartz bow. This instrument is very convenient where sensitivities of the order of magnitude of 2 volts per division, and working ranges of about 20 to 250 volts are required.

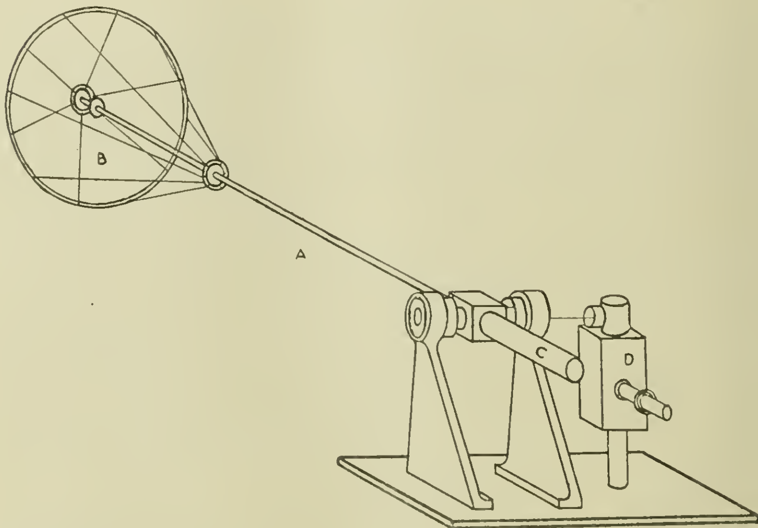
Another convenient form of quartz-fibre electroscope of a design devised by Wulf, comprises a single platinized quartz fibre attached at its lower end to a quartz bow and at its upper end to the main terminal of the instrument. Two insulated metal plates are mounted with their planes parallel to each other and to the quartz fibre, one plate being mounted on each side of the fibre. The case of the instrument being earthed, these plates may be charged respectively to +100 and −100 volts, or to any convenient amount by batteries, and a charge communicated to the fibre will then cause a deflection. The deflection for a given potential applied to the fibre increases with the field between the plates, and with diminution of tension on the fibre, which latter may be varied by moving the bow support up and down by means of a suitable screw. In the laboratory it is not difficult to obtain a sensitivity of 100 divisions per volt, although on board ship a sensitivity of from 5 to 10 divisions per volt is found more desirable. On account of their freedom from the effects of tilt, and on account of their small electrical capacities, these two types of electroscope have been found the most convenient forms for use at sea.

*Potential-Gradient.*—In former work on both land and sea, the customary method of measuring the potential-gradient has been the following:

An insulated rod is caused to project from the wall of a house, or the rail of the ship, as the case may be, and, to the external end of the rod, a plate coated with radioactive material is attached. The other end of the rod is attached to an electrometer or electroscope. Now, on account of the potential-gradient, there is ordinarily a difference of potential between the wall of the house (or the rail of the ship) and a point some distance away from it. The radioactive plate renders the air in its immediate vicinity conducting, and electricity consequently flows to the rod until it attains the potential of the air at its external end, as determined

by the electrical field of the earth, modified by the presence of the apparatus itself. The quantity measured by the electrometer may be looked upon as proportional to the potential-gradient; and, in order to obtain absolute values, it is necessary to make a set of measurements simultaneously over some flat surface in such a manner that the measurements are independent of the distortion brought about by the apparatus itself. The chief disadvantages associated with this form of apparatus for work aboard ship lie in the slowness of its action, which necessitates very perfect insulation if accurate results are to be obtained. Further, since

FIG. 3.




the motion of the ship continually alters the distance between the end of the rod and the water, the potential recorded can only be looked upon as a sort of average. In order to overcome these difficulties, the apparatus illustrated in Fig. 3 was constructed. The instrument consists of a brass tube *A* fixed at one end to an axle, so that it can rotate in a plane containing the fore-and-aft line of the ship. The axle is mounted on supports fixed to the stern rail of the ship, and the projecting end of the brass tube carries a disc *B*, made in the form of a skeleton of a parasol, and covered with gauze not shown in the figure. The handle *C*, by which the rotation is brought about, is insulated from the axle.

and the latter is itself insulated from earth by causing it to work in brass tubes fixed into their supports with sulphur insulation. The axle is connected by a thin wire to a Wulf bi-filar electroscope *D*, the wire and axle being in the same line. It is arranged that, when the brass tube is vertical and the parasol attachment downward, the electroscope system is earthed. On rotating the tube to some other position, fixed by a stop, a deflection proportional to the potential-gradient is obtained in the electroscope. Insulation difficulties are entirely overcome, since the leakage occurring during the turning of the handle from one position to another is negligible. Further, the operation can be performed so quickly that readings may always be taken at the same position of tilt of the ship as determined by a spirit level.

*Conductivity and Ionic-Content.*—The conductivity contributed to the atmosphere by the ions of either sign is the product of the number of these ions per c.c. the charge on an ion, and the ionic mobility, which is the velocity which the ion would attain under unit electric field. The method which is usually employed for measuring the conductivity of the air is that due to Gerdien. In this method, air is drawn by a fan through the space between two concentric cylinders, the central member of which is charged and connected to an electroscope. The theory of the instrument shows that, so long as the velocity of the air-current is large enough to insure that the central cylinder is unable to extract from the air all of the ions which it attracts as the air passes through, the rate of loss of charge by the cylinder is independent of the air velocity, and depends only upon the conductivity contributed by the ions of sign opposite to the charge on the central cylinder. Under these conditions, measurements of the potential of the central cylinder at two different times during the passage of the air current, combined with the knowledge of certain electrical capacities associated with the instrument, enable the conductivity in question to be deduced. If the velocity is so small that all of the ions of sign opposite to that on the central cylinder are drawn thereto as the air passes through, the indications of the instrument do depend upon the velocity of the air; in fact, the rate of loss of charge is proportional to the velocity of the air under these circumstances, since the air is robbed of all of its ions as it passes through the space between the cylinders. A knowledge of the rate of flow of the air then enables one to deduce, from the

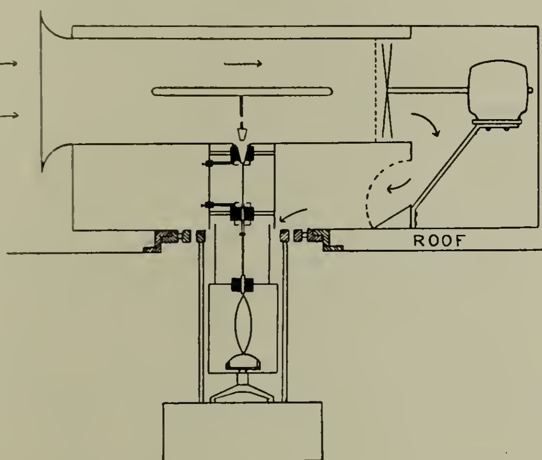
indications of the instrument, the number of ions per cubic centimetre. The chief disadvantage of this type of instrument for measuring the ionic densities lies in its lack of sensitivity. In the usual form of instrument, the central cylinder is connected to a Wulf electroscope of the bi-filar type reading up to about 200 volts, and the outer cylinder is earthed. The rate of movement of the fibres when the air flows through the instrument under these conditions is extremely slow, and as much as half an hour may be necessary to obtain a single satisfactory observation. The result of this is that, in some measurements—for example those of ionic mobilities, in which it is necessary to assume constancy of the ionic content of the atmosphere over the period of two measurements—the departure from this condition is frequently sufficient to cause the quantity measured, which is essentially a positive quantity, to come out negative in the calculations.

In order to increase the sensitivity and rapidity of action of the instrument, I devised a modified form, in which the central cylinder of the apparatus is connected to the fibre of a unifilar electroscope of the Wulf type, the sensitivity of which is made as great as is desired. The potential of the fibre is never allowed to depart far from zero, and the necessary field is obtained by insulating and charging the outer cylinder to about 150 volts. On releasing the fibre from earth it, of course, starts to move at a rate determined by the rate of supply of electricity to the central system from the air. The fact that the central system is never allowed to depart far from zero potential also enormously reduces the leakage error, which otherwise would become a very serious consideration, especially in work at sea. Indeed, leakage may be entirely compensated by starting observations with the fibre charged in such a sense that it crosses the zero point during the observation, for it may then be arranged that the fibre readings which are chosen as the bases of the measurements lie at equal distances on each side of the zero. In order to avoid an alteration of the number of ions entering the apparatus, by the charge on the outer cylinder, the latter is surrounded by yet another cylinder which is insulated from it and earthed. Even this does not entirely overcome the difficulty, however, as will readily be surmised when it is remembered that the potential of a point a short distance outside the cylinder is zero, and that of a point a short distance inside is about 150 volts, so that the ions, in order to get

in, have to move in opposition to electric forces. In order to completely eliminate this difficulty, the central cylinder is provided with an additional attachment which it is unnecessary to describe here.[6]

Except in matters of detail, the method of measuring the conductivity on the *Carnegie* is the same as that due to Gerdien. The fan is, however, driven by an electric motor instead of by hand, so that a larger current of air is obtained, and greater sensitivity can be secured by the employment of a higher potential on the central system than would be otherwise possible. The apparatus is illustrated in Fig. 4.

FIG. 4.




Since good insulation is essential to such measurements as these, it is desirable that the parts of the apparatus which contain insulating materials shall be well protected. For this reason, a small observatory has been erected aboard the *Carnegie,* and this observatory houses the apparatus for the measurement of conductivity, ionic density, penetrating radiation, and part of the apparatus for the determination of the radioactive content of the atmosphere. It is arranged that the cylinders which receive the air project through the roof of the observatory, but the electroscope systems are mounted permanently inside. The advantage of this arrangement lies in the fact that, in so far as the temperature of the inside of the observatory is always above the dew

[6] *Terr. Mag.,* vol. xix, p. 171, 1914.

point of the air outside, condensation on the insulated parts is less likely to occur than if the apparatus were exposed to the open air.

*Measurement of the Penetrating Radiation.*—For the measurement of the number of pairs of ions produced per cubic centimetre per second in a closed vessel, an air-tight copper vessel of 27 litres capacity is employed. A rod which is insulated from the copper vessel is connected to the fibre of a unifilar electroscope. The copper vessel is charged to a potential sufficiently high to cause saturation for the ionization produced inside, so that on releasing the fibre from earth, the central system charges up at a rate determined by the rate of production of ions in the vessel. The insulating material separating the central rod from the vessel is, of course, divided into two parts by a guard ring which is earthed, thus minimizing leakage from the copper vessel across the amber. The whole apparatus is mounted on a gimbal.

*Measurement of the Radioactive Content of the Atmosphere.*—In measurements of the radioactive content of the atmosphere, former investigators have largely used a method due to Elster and Geitel. This method, which depends for its action upon the fact that the products of disintegration of the radium emanation in the air are for the most part positively charged, consists in allowing a long negatively charged wire to collect active material from the atmosphere for a period of two hours, and then measuring the saturation current which this active material produces when wound on a frame and introduced into an ionization chamber. In this way are obtained quantities from which a sort of comparison may be made of the amounts of radioactive material in the atmosphere at different places. The theory of the method shows, however, that, apart from the fact that the results given are only relative, considerable uncertainty attaches to their interpretation.

Undoubtedly one of the best methods of determining the radium-emanation content of the atmosphere is that which utilizes the fact that when air containing emanation is drawn over cocoanut charcoal, the emanation is absorbed. The emanation is subsequently expelled by heating, and is measured by its ionizing action. The time required in carrying out this method, and the nature of the apparatus necessary, is such as to render the method impracticable for use aboard ship. The method employed on the

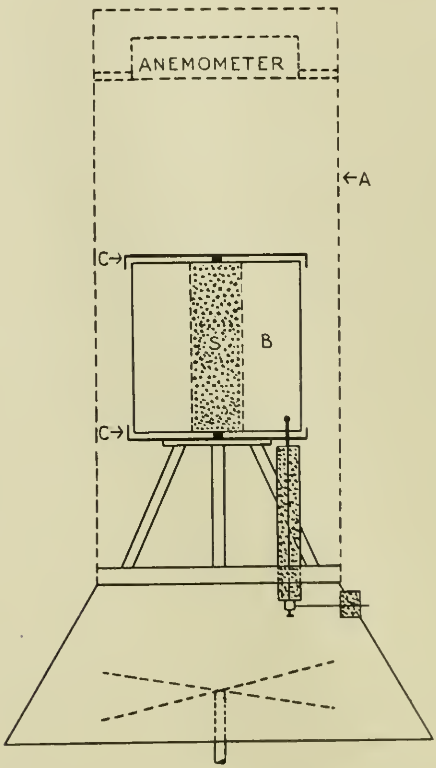
*Carnegie* consists in drawing air between two concentric cylinders the central one of which is charged negatively to such a high potential that all of the active carriers entering the concentric cylinders are brought to the central system. The saturation current produced in an ionization chamber by the active deposit collected in a given time, combined with a knowledge of the air-flow during the deposit, enables the amount of active material per cubic metre of air to be estimated. The considerations and calculations involved in the deduction of the absolute value of the radioactive content are too complex to be given here in detail. The general principle of this method has been used in one form or another by several investigators on land, and the principal modifications which have been introduced in the apparatus on the *Carnegie* have been made with the object of rendering the results more susceptible of accurate theoretical interpretation, and of increasing the sensitivity of the apparatus and its adaptability for use at sea.

The collecting apparatus as at present employed is shown in its essential features in Fig. 5. It consists of a copper cylinder *A*, 64 cm. long and about 20 cm. in diameter, with an anemometer at one end and a fan at the other. The central system consists of an insulated wooden cylinder *B*, 12 cm. long, supported by a rod passing through its axis and insulated from it by sulphur *S*. The surface of the wooden cylinder is covered by copper foil, held on by rubber bands, and it is on this foil that the deposit is collected. Earthed metal caps *CC* attached to the central rod fit over the top and bottom of the central cylinder without touching it, and insure that the deposit of the active material is confined to the copper foil.

A large air current is necessary if a large amount of deposit is to be obtained; and, in order to secure saturation with a reasonably low potential on the central cylinder it is necessary that the latter shall be large. A large cylinder when subsequenly introduced into the ionization chamber, so as to form the central system there, would reduce the sensitivity in the ionization measurements, however, on account of the large capacity. For this reason, the central system of the ionization chamber is formed of a thin rod, and the foil, after removal from the inner cylinder of the collecting apparatus, is bent over and made to line the walls of the ionization chamber, with the active surface facing inwards. In this way the foil does not contribute to the capacity of the system. The height of the ionization chamber is about twice that

of the foil cylinder, so that the latter covers only the central portion of the wall of the chamber. In this way are avoided difficulties arising from uncertainties which would otherwise be introduced in a knowledge of the fraction of the $\alpha$ particles travelling any assigned portion of their range in the vessel. The central system of the ionization chamber is attached to a unifilar electro-

FIG. 5.




scope, and the potential is applied to the outer vessel, the whole being mounted on a gimbal.

The radioactive content of the sea water is obtained by evaporating samples of the water to dryness and sending the residues to Washington, where the activities are determined.

It has been my object to give a brief description of the methods and appliances used on the *Carnegie's* fourth cruise as an illustration of the general processes which one must employ in work of

this kind. I will not, however, here enter into a general discussion of the results of that cruise, for, to do so would devote, to a special field, too great a proportion of a lecture in which the subject of atmospheric electricity in general is the main theme. I have given a discussion of the results, and a more complete account of the instruments and methods in a paper "Results of Atmospheric-Electric Observations Made Aboard the *Galilee* (1907–1908), and the *Carnegie* (1909–1916)," [7] to which I will refer those interested in fuller information on the subject. I cannot leave this matter, however, without paying a tribute to the energy and enthusiasm of the various observers, who, in spite of the most severe climatic conditions, for example in the tempestuous regions of the sub-antarctic oceans, labored with such faithfulness to make the atmospheric-electric work of the cruise a success.

### THE MAINTENANCE OF THE EARTH'S CHARGE.

I now come to the all-important question of the origin and maintenance of the earth's charge. The earth is continually losing negative electricity owing to the action of the potential-gradient operating in the conducting atmosphere. The current from a square centimetre of the earth's surface is only about $2 \times 10^{-16}$ amperes. The current from the whole earth is only about 1000 amperes, or about as much as is taken by 3000 incandescent lamps. It is nevertheless sufficient to insure that 90 per cent. of the earth's charge would disappear in ten minutes if there were no means of replenishing the loss. How then is the loss replenished?

One of the earliest suggestions was made by G. C. Simpson, who supposed, tentatively, that the sun emitted positive and negative corpuscles of a very high penetrating power. He further supposed that the penetrating power of the negative corpuscles was greater than that of the positive corpuscles, and sufficient to enable them to reach the earth's surface, while the positive corpuscles were caught by the atmosphere. In this way the attempt was made to account for the negative charge of the earth and the positive charge of the atmosphere.

[7] From Publication No. 175 (vol. iii) of the Carnegie Institution of Washington. This paper, which is published in the joint names of the Director of the Department of Terrestrial Magnetism and the present writer, contains, in addition, a compilation of the reports of observers on previous cruises of the *Carnegie* and *Galilee*.

As a matter of fact, it is unnecessary to go to any special pains to account for the positive charge in the atmosphere provided that we can account for the maintenance of the negative charge on the surface of the earth. For, it is an experimental fact that the atmospheric conductivity increases with altitude until its value at an altitude of nine kilometres is about thirty times the value at the earth's surface. It follows from this that if the potential-gradient were the same at an altitude of nine kilometres as it is at the earth's surface, more negative electricity would be driven outwards through a sphere at the altitude of nine kilometres and concentric with the earth than would be driven out of the earth's surface into the atmosphere. The shell of air below the altitude in question would consequently acquire a positive charge, so that the potential-gradient at the altitude of nine kilometres would become less than that at the earth's surface. The process would continue until the diminution of potential-gradient with altitude was just sufficient to compensate for the increase of conductivity with altitude so as to leave the conduction current-density independent of altitude.

The chief objection to Simpson's tentative theory, however, is one which he himself supports in a recent publication,[8] viz., that it postulates a degree of penetration for the corpuscles so enormously great compared with any corpuscular penetration we have become acquainted with in the laboratory, since the suggestion was put forward, that one hesitates to make this hypothesis without further evidence of the existence of such a degree of penetration.

An early suggestion as to the origin of the earth's charge came from C. T. R. Wilson. It is known that, under suitable conditions, ions may act as nuclei for the promotion of condensation of water vapor; and, since water condenses more readily upon the negative than upon the positive ions, Wilson argued that rain should be, on the average, negatively charged. It is true that rain is charged; but it is charged sometimes negatively and sometimes positively; and, unfortunately, it appears that 75 per cent. of the charge brought down by rain is of the positive sign; that is, of a sign opposite to that required by the theory. Apart from this, however, there are several fatal objections to a theory of this

[8] "Some Problems of Atmospheric Electricity." *Monthly Weather Review*, vol. xliv, pp. 115–122, 1916.

kind. In the first place, the fundamental hypothesis as to the condensation of water vapor upon the ions cannot be substantiated in the case of the atmosphere; for theory requires that, in order that water vapor shall condense upon an ion, and grow to a drop of appreciable size, there shall be at least a four-fold degree of saturation, and such a condition of affairs is never attained in the atmosphere. Again, if we suppose the replenishment to take place through the agency of rain, a positive charge equal to the negative charge which has been given to the earth must remain in the particular portion of the atmosphere from which the rain happens to have come at the time. This positive charge will hold the corresponding negative charge at the portion of the earth's surface immediately below it, so that elsewhere, at places where rain is not falling, there will be no potential-gradient. The difficulty in respect of this latter matter is slightly reduced if we postulate the existence of a very highly conducting layer in the upper atmosphere. For, in this case, a separation of opposite charges between earth and cloud will tend to bring about, by induction, a difference of potential between the highly conducting layer and the earth's surface; and this resulting difference of potential will become distributed equally over the whole surface, on account of the high conductivity of the layer.

A theory which has attracted a great deal of attention is one originated by Elster and Geitel, and subsequently modified by Ebert. If ionized air is allowed to pass through a fine tube, it is found, under certain conditions, that the negative ions diffuse to the walls of the tube more rapidly than the positive ions, with the result that the air which emerges is positively charged. Applying this idea to the atmospheric-electric problem, Ebert argued that the air within the pores of the ground must be highly ionized on account of the radioactive material in the soil, and that during the periods of falling barometric pressure this air would come out of the pores into the atmosphere, acquiring a positive charge in the process on account of the smaller coefficient of diffusion of the positive ion. In this way Ebert supposed that the earth would acquire a negative charge and the atmosphere a positive charge. It is, at first sight, a little difficult to see how the positive charge could rise to any appreciable altitude in opposition to the attraction of the negative; but, in order to account for this, Ebert invoked the assistance of rising currents of air. The theory has

been severely criticized by G. C. Simpson, principally on the basis of conclusions drawn from his laboratory experiments, to the effect that the charging influence arising from the diffusion phenomenon would be far too small to account for the required effect.

Again, according to the theory, there should be an upward convection current of positive electricity equal in total amount to the negative conduction current. By utilizing data on the density of the positive charge in the atmosphere, and on the upward convectional velocity, Gerdien has concluded that the latter is far too small to account for the necessary convection current. Quite apart from these considerations, however, it may be shown that,[9] even if the process did take place according to the method supposed by Ebert, the rising charge of positive electricity would become absorbed by the action of the negative conduction current by the time the air had risen to a comparatively small altitude, so that practically the whole of the positive charge in the atmosphere would be confined to a comparatively thin shell (of thickness less than a kilometre for example) near the surface of the earth. The potential-gradient would consequently attain a sensibly zero value at an altitude less than one kilometre, and this we know to be contrary to the facts.

Other objections to the theory are that it provides no satisfactory explanation for the existence of the potential-gradient over the sea, where there is certainly no diffusion phenomenon to support the process. Neither does it provide satisfactorily for the continuation of the process during the periods when the barometer is not falling. In common with all theories which attempt to account for the phenomena by supposing a supply of negative to the earth and positive to the atmosphere at one place, it is confronted with the difficulty that the positive in the atmosphere tends to hold the negative on the particular portion of the earth immediately beneath it, so that at other places the potential-gradient should be zero. It is of little use to invoke the aid of the wind for the transportation of the positively charged air to regions where the replenishing action is not taking place, for theory shows that, owing to the conductivity of the air, this charge would disappear with great rapidity when the air carrying it had passed out of the region of replenishment.[9] In fact, the only way of

[9] W. F. G. Swann: "On the Origin and Maintenance of the Earth's Charge." *Terr. Mag.*, vol. xx, pp. 105–126, 1915.

accounting, even in part, for a distribution of potential-gradient over the earth's surface as a result of actions occurring at isolated places or periods, is to fall back upon the assumption of a very highly conducting layer in the upper atmosphere, as I explained when discussing C. T. R. Wilson's condensation theory.

The two most striking phenomena of atmospheric electricity requiring an explanation are the existence of the "Penetrating Radiation," and the origin of the earth's charge. It would be a distinct gain if we could reduce these two problems to one; if, for example, we could show that, whatever may be the explanation of the "Penetrating Radiation," provided only that we are willing to take its existence as an experimental fact, the maintenance of the earth's charge must follow as a necessary consequence. I think that there is perhaps some hope in this direction along lines which I shall endeavor to explain.

I must first recall to you one or two facts in relation to the ionization produced by $\gamma$ rays. It will be recalled that ionization consists in the expulsion of an electron from a neutral atom by the ionizing agency. Now we know as an experimental fact that when $\gamma$ rays ionize, the electrons which are emitted are shot off almost entirely in the direction of the incident $\gamma$ rays, at least this is so for atoms of comparatively small atomic weight. Thus, for example, to quote some results by W. H. Bragg, it is found that if $\gamma$ rays are allowed to fall upon a plate of carbon, 95 per cent. of the emitted electrons come off from the side of the plate at which the $\gamma$ rays leave the carbon. The more penetrating the rays, the more pronounced the effect; further, the more penetrating the rays, the greater the speed and penetrating power of the electrons which are shot off. Now remembering these facts, what sort of action may we expect to be exhibited by the penetrating radiation which comes from above, supposing it to partake of $\gamma$ ray properties? We may expect that when the penetrating radiation emits an electron from an atom of air, in the process of ionizing, that electron will be emitted almost entirely in a downward direction. Further, the great penetrating power of the penetrating radiation will insure that the electrons emitted will travel considerable distances in the atmosphere before they come to rest. Thus, in each layer of air, we shall have emissions of electrons in a downward direction, by the penetrating radiation from above, and absorption of electrons which have

been emitted by the penetrating radiation from the layers of air above. The earth's surface will receive electrons from the layers of air which are, so to speak, in striking distance of it, and it will consequently acquire a charge. As this charge grows, an electric field will be set up, and the charge will increase until this field has attained a value such that, owing to the conductivity of the atmosphere, as much negative electricity is returned to the various layers of air as is shot out of them by the action of the penetrating radiation. At each point of the atmosphere, there will consequently be a downward current of electrons which have been given high velocities by the penetrating radiation; this we shall refer to as the corpuscular current; and, there will be an ordinary conduction current which, while it involves both positive and negative ions (moving in opposite directions), has the effect of transferring the negative electricity back to the atmosphere. When a condition of equilibrium has been attained, the corpuscular current density must balance the conduction current density, and it will be interesting, from this standpoint, to submit the theory to examination as regards order of magnitude.

Taking for the purpose of illustration a simplified case where the penetrating radiation considered is all directed vertically downwards, if $q$ is the number of electrons liberated per c.c. per second by the penetrating radiation, and $h$ the average distance which an electron travels from its point of origin, in the original direction of its motion, the corpuscular current density will be $qeh$, so that if $i$ is the conduction current density, we should have:

$$i = qeh$$

where $e$ is the electronic charge. If we take account of the fact that the penetrating radiation comes from all directions contained within a hemisphere, the effect is merely to introduce a factor 0.5 on the right-hand side.

Suppose now we put for $q$, the value 3, which is approximately equal to the portion of the ionization per c.c. per second in a closed vessel, which is due to the radiation from above. Then putting $i = 6.5 \times 10^{-7}$ electrostatic unit, which is the average value from a large number of observations, and $e = 4.8 \times 10^{-10}$, we find that $h$ must be 9 metres.

Now 9 metres is by no means a large range of path to assume for electrons which are emitted by a radiation as penetrating as

the "Penetrating Radiation": for Eve has found $\beta$ rays from radioactive substances having ranges as large as 7 metres.

The theory is attended by one difficulty which is not, I think, vital, however. We know that electrons which are emitted from atoms with high speed will themselves ionize a gas through which they pass, so that, ought we not to conclude that the very high-energy electrons which are emitted by the penetrating radiation would themselves produce many more ions in the atmosphere? Ought we not to conclude, in fact, that the three ions per c.c. per second which we have taken as the basis of our calculations represent the net ionization produced by the ejection of the original electrons and the ionization which these electrons themselves produce subsequently. An ordinary $\beta$ ray produces about 40 ions per centimetre of its path, so that, in its whole journey in the atmosphere, it produces a very large number of ions. If we adopt this view as to the ionization by the electrons originally ejected by the penetrating radiation then, quite apart from all questions of the origin of the earth's charge, our views as to the meaning of the measurements made in closed vessels will require very careful scrutiny. A close examination of the matter shows, however, that our primary difficulty may not be as great as at first sight appears to be the case. Although the velocity of light represents the greatest velocity which an electron can have, and ordinary $\beta$ rays have velocities 95 per cent. and more of this velocity, we must not too readily assume that there is practically no difference between the behavior of an electron with velocity, say, 98 per cent. of the velocity of light, and one with velocity 99.8 per cent. of that velocity for example. For theory shows that certain properties which are characteristic of the fields of high-speed corpuscles only commence to make their appearance when the velocity attains a value very near to that of light. With electrons of moderate $\beta$ ray velocity there is, of course, no question as to the fact that ionization does occur all along the path; but, though the considerations involved are too complex for brief presentation, it may be remarked that the theoretical properties of electrons of very high energy are such as to suggest that they may not fritter away their energy in ionization as readily as do those with moderate $\beta$ ray energy. It may be that when an electron is emitted from a molecule by a radiation as hard as the penetrating radiation, it travels through the air without ionizing the molecules, and without, in

general, suffering any appreciable change in its energy; but that if the conditions of encounter with a molecule are favorable, it becomes completely absorbed by the molecule, and in so doing, sends out a radiation of a type similar to that which caused its emission from the parent atom. To those who are familiar with modern developments along the line of the "Quantum Theory," a view of this kind will probably appear much less visionary than it would do on the basis of our earlier views.

It may be remarked that the difficulty I have discussed, with regard to the question of ionization by the high-energy electrons, is one which would be felt in any theory in which such electrons are invoked. It would appear, for example, in the case of Simpson's tentative suggestion as to the maintenance of the earth's charge by corpuscles emitted from the sun.

### THE ORIGIN OF THUNDERSTORMS.

It would be easy to devote the whole of this lecture to the subject of thunderstorms, so the treatment to which I shall confine myself must necessarily be brief. The theory which has been most successful in explaining the facts is that suggested by G. C. Simpson. The theory has also received considerable development on the meteorological side in the writings of W. J. Humphreys in the Journal of the Institute.

The theory is founded on the experimental fact that if water is broken into drops by allowing it to fall upon a rising column of air, the drops are found to be positively charged while the air receives a negative charge. Now experiment has shown that it is impossible for drops of water to fall through air which is rising with a velocity greater than 8 metres per second. If the drops are very small they will be blown up by a rising column of air, and it is in general necessary for a drop to have a certain minimum mass before it can fall through a column of air rising with specified velocity. If the velocity is as high as 8 metres per second, however, the size which the drop would have to attain in order to fall through the column would be so great that the drop would be broken up by the air stream, even if it succeeded in attaining the necessary size temporarily. The smaller drops formed as a result of the disintegration would, of course, be carried upwards by the air stream.

Now it is a matter of common experience that thunderstorms are always preceded by high winds, and a close examination of

the phenomena shows that, in the storms which give rise to electrical discharges, columns of air are to be found rising with very considerable velocity. We may liken one of these columns of air to an hour-glass, or dice box. At the bottom the column is wide, and the velocity is small. At the narrowest part of the column the air attains its maximum velocity, while at the top it fans out and the velocity again becomes small. Now in the period prior to a thunderstorm, the air is very humid. As this air rises and becomes cooled in the process, it eventually reaches a temperature at which drops of water begin to condense out. At first, these drops are carried upwards with the stream; but, as they grow, they eventually reach a size at which they start to fall. Suppose that when this occurs, the drops are some distance above the narrowest part of the air column. Then, as they fall and continue to grow in size they eventually reach a place where the velocity is sufficiently great to break them up. The smaller drops become positively charged in the process and the air receives a negative charge. The small drops now start their ascent again, although, of course, with velocity less than that of the air. As they rise they grow, and eventually the whole process is repeated again. The cycle may be gone through several times, the drops becoming charged more and more each time. The free negative ions which ascend with the rising air eventually coalesce with the finer water drops to be found at the top of the cloud, so that we eventually attain a state of affairs in which the water at the top of the cloud is highly charged negatively, while that in the middle of the cloud is highly charged positively. When the accumulations of charges are sufficient to result in a field which will break down the insulation of the air at some point, a lightning flash follows. It thus appears that the high winds which are associated with the thunderstorm are in no sense a result of the electrical manifestations; the electrical phenomena are themselves secondary features resulting from the air motion.

During the turbulence associated with the storm, some of the large drops of positively charged rain which have gone through the cycle of breaking and reformation several times get carried to places where the velocity of the upward current is not sufficient to break them up, and they fall to earth. In this way we find the explanation of the experimental fact that the heavy rain of the thunderstorm is found to be positively charged. On the other hand, the rain which accumulates at the top of the cloud, and

which is negatively charged is of the finer type, and may be expected to fall to earth only in the lulls between the periods of most violent activity, or at places somewhat remote from the storm centre. Here, again, experiment supports the conclusions in showing that the finer rain which falls during the quiet periods of the storm is negatively charged.

Of fire-balls, thunderbolts and the like, time forbids me to speak. These very interesting phenomena have been discussed very clearly in Professor Humphrey's articles, "The Thunderstorm and Its Phenomena,"[10] published in the Journal of this Institute; and, it will suffice to say that, in spite of the fantastic behavior which is sometimes attributed to these more rare attendants of the thunderstorm, there does not appear to be anything which is not capable of explanation in terms of our modern views of electrical phenomena.

From time immemorial, the thunderstorm has been the emblem of all that is gigantic, mysterious, and awe-inspiring in the manifestations of nature's power; and, there is perhaps an element of poetic justice in the fact that this monster's secrets have been among the first of the greater problems of atmospheric electricity to be satisfactorily unveiled. Cosmical physics as a whole has gained less from the fruits of modern advances than have the more purely laboratory sciences. The discovery of the electron, and the development of the electrical theory of matter have indeed revolutionized our notions of how things happen in molecular physics; and atmospheric electricity has reaped as much advantage from the work of the past thirty years as perhaps any other branch of cosmical physics. Yet, when we think of the great detail in which modern theory coördinates most of the more intricate and less obvious facts of chemistry and physics, it is rather staggering to recall how many problems of a cosmical nature are yet far from a satisfactory explanation. How long will gravitation and the origin of the earth's magnetic field continue to baffle all who ponder over nature's mysteries! How long will the great science of meteorology, including atmospheric electricity continue to hold back some of its most striking secrets! And, when these have succumbed to the onward progress of science, when, if ever, shall we hope for that great consummation of man's scientific effort—the coördination into the general scheme of things of the greatest puzzle of them all, the mystery of organic life!

[10] Journal of The Franklin Institute, November and December, 1914.

# OPTICS OF THE AIR.*

BY

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## Chapter IV.

### REFRACTION PHENOMENA: REFRACTION BY ICE CRYSTALS.

*Introduction.*—The cirrus clouds and others formed at temperatures considerably below 0° C. usually consist of small but relatively thick snowflakes with flat bases, or ice spicules with flat or, rarely, pyramidal bases, always hexagonal in pattern and detail, as shown by Fig. 151 from Bentley's remarkable collection of photomicrographs of snow crystals.

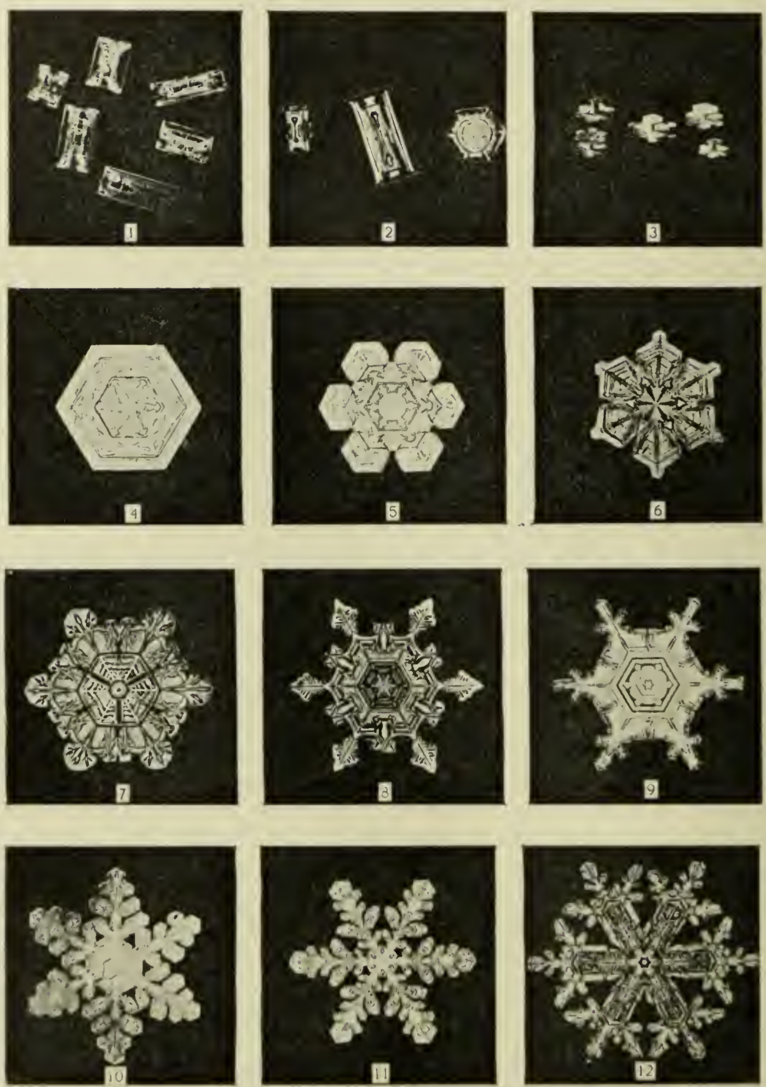
Light from the sun, for instance, obviously takes many paths through such crystals and produces in each case a corresponding and peculiar optical phenomenon. Several of these phenomena, the halo of 22° radius, the halo of 46° radius, the circumzenithal arc, parhelia, etc., are quite familiar and their explanations definitely known. Others, however, have so rarely been seen and measured that the theories of their formation are still somewhat in doubt. Finally, many phenomena, theoretically possible, as results of refraction by ice crystals, appear so far to have escaped notice.

*Prismatic Refraction.*—Since the phenomena caused by the passage of light through ice crystals are numerous, it will be most convenient, in discussing them, first to obtain general equations for prismatic refraction, and then to substitute in these equations the numerical constants applicable to each particular case.

*Deviation.*—Let $A$ (Fig. 152) be the angle between two adjacent faces of a prism; let $CE$ be the path of a ray of light in a plane normal to their intersection (direction of travel imma-

* Continued from page 488, Vol. 188, October, 1919.

FIG. 151.




Snow crystals (Bentley).

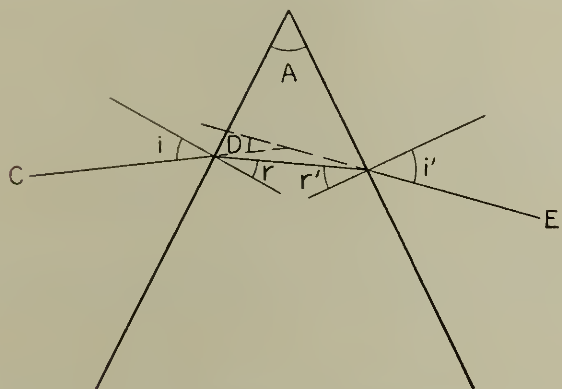
terial) ; let $i$ and $i'$ be the angles of incidence and $r$ and $r'$ the corresponding angles of refraction. Then the change in direction, $D$, of the ray is given by the equation,

$$D = i + i' - (r + r') = i + i' - A \ldots\ldots\ldots\ldots (1)$$

*Minimum Deviation.*—Minimum deviation occurs when $\frac{dD}{di} = 0$ and $\frac{d^2D}{di^2} > 0$ But when

$$\frac{dD}{di} = 1 + \frac{di'}{di} = 0, \; di = -di'.$$

FIG. 152.




Deviation by refraction.

and as

$$r + r' = A, \quad dr = -dr'.$$

Also, from the law of refraction,

$$\sin i = \mu \sin r.$$
$$\sin i' = \mu \sin r'$$

Hence, directly,

$$\frac{\sin i}{\sin i'} = \frac{\sin r}{\sin r'},$$

or

$$\sin i \sin r' = \sin i' \sin r$$

and, by differentiation, if $di = -di'$, and $dr = -dr'$,

$$\frac{\cos i}{\cos i'} = \frac{\cos r}{\cos r'},$$

or

$$\cos i \cos r' = \cos i' \cos r.$$

By addition, $\cos\,(i-r)=\cos\,(i'-r)$, or $i-r'=i'-r$.
By subtraction, $\cos\,(i+r')=\cos\,(i'+r)$, or $i+r'=i'+r$.

Hence, if, as assumed, $\frac{dD}{di}=0$,

$$i = i', \text{ and } r = r' = \frac{A}{2}.$$

From

$$\frac{dD}{di}=1+\frac{di'}{di}=1+\frac{\dfrac{\mu\cos r'\,dr'}{\cos i'}}{\dfrac{\mu\cos r\,dr}{\cos i}}=1-\frac{\cos i\cos r'}{\cos i'\cos r},$$

it follows, by a little reduction, that when $\frac{dD}{di}=0$

$$\frac{d^2D}{di^2}=\frac{\mu\cos^2 r\sin i' - \cos^2 i\sin r}{\mu\cos i\cos^2 r}.$$

But

$$\mu>0,\ \cos^2 r>\cos^2 i,\ \sin i>\sin r, \text{ and } \mu\cos i\cos^2 r>0.$$

Hence, when

$$\frac{dD}{di}=0, \text{ that is, when } r=r',\ \frac{d^2D}{di^2}>0$$

and the deviation has its minimum value.

Writing $D_0$ for the minimum deviation, it follows that

$$D_0 = 2i - A. \quad \text{- - - - - - - - - - - - - - - - (2)}$$

Hence, from $\sin i=\mu\sin r$, and $r=\frac{A}{2}$, we get

$$\sin\frac{D_0+A}{2}=\mu\sin\frac{A}{2} \quad \text{- - - - - - - - - - - - - - (3)}$$

Maximum deviation, $D_m$, obviously occurs when

$$i = 90°,$$

or, since $\mu$ for ice $=1.31$, when $r=49°\ 46'$.

Since

$$D = i + i' - A$$
$$D_m = 90° + i' - A$$

and

$$\sin\,(D_m + A - 90°) = \mu\sin r' = \mu\sin\,(A - 49°\ 46')$$

or

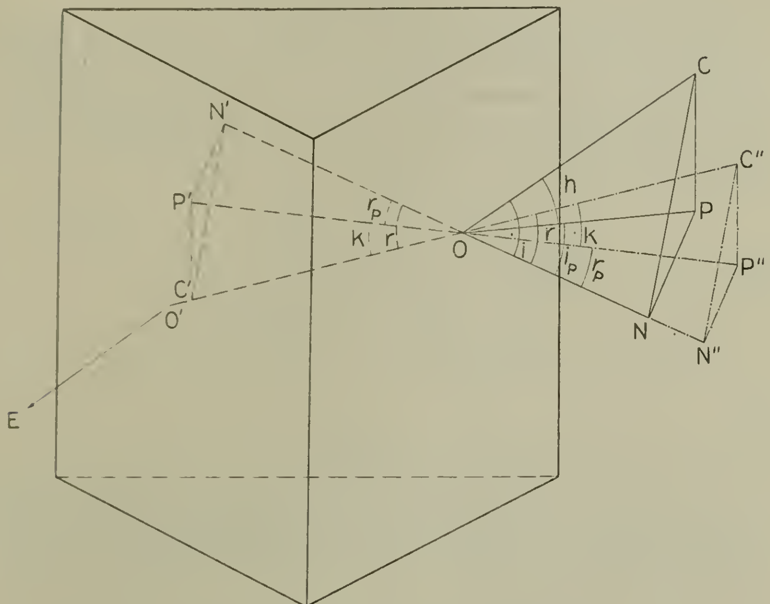
$$\cos\left[(180° - A) - D_m\right] = \mu\sin\,(A - 49°\ 46') \quad \text{- - - - - - (4)}$$

The above equations apply only to refraction in a plane normal to the intersection of the faces of the prism. When the incident ray is inclined to this plane, the effective angle of refraction is increased, and as such inclination usually occurs in the case

of floating ice crystals it is necessary, in the study of halos, to evaluate its effect on the deviation.

Let the ray, $CE$ (Fig. 153), enter a prism at $O$ and leave it at $O'$. Let $ON$ be the normal to the prism face at $O$, and let $OP$ be the projection of $CO$ onto a plane through $O$ normal to the intersection of the refracting faces. Let $P$ be the projection of

FIG. 153.




Refraction of rays inclined to principal plane.

$C$, and let the plane $CNP$ be normal to $ON$. Similarly, let $P'$ be the projection of $C'$ on the principal plane, $PON$, and let the plane $C'P'N'$ be perpendicular to the normal $ON$ extended; then, since the refracted ray $OC'$ lies in the plane $OCN$, it follows that the triangles $CNP$ and $C'N'P'$ are similar.

Therefore,

$$\frac{\sin h}{\sin k} = \frac{\sin i}{\sin r},$$

and

$$\sin h = \mu \sin k,$$

in which $h$ and $k$ are the angles between the ray and principal plane before and after refraction, respectively.

Similarly, if $h'$ and $k' = k$ are the angles at $O'$ corresponding to $h$ and $k$ at $O$,

$$\sin h' = \mu \sin k' = \mu \sin k.$$

Hence,

$$h = h'$$

That is, the inclination of the ray to a principal plane is the same after leaving a prism as before entering it.

Let $i_p$ be the angle between the normal, $ON$, and the projection, $OP$, of the ray, $CO$, on the principal plane through $O$, and $r_p$ the angle betwen the normal extended, $ON'$, and the projection, $OP'$ of the refracted ray, $OC'$, onto the principal plane. Then (perhaps better seen by reversing $OC'N'P'$ to $OC''N''P''$),

$$\sin i_p = \frac{NP}{OP} = \frac{NP}{OC \cos h},$$

and

$$\sin r_p = \frac{N''\,P''}{O\,P''} = \frac{N''\,P''}{OC'' \cos k}.$$

But $NP = \frac{OC}{OC''}\,\mu\,N''\,P'' = \mu\,N''\,P''$ if $OC = OC''$,

and

$$\sin i_p = \mu \frac{\cos k}{\cos h} \sin r_p .$$

Hence, rays inclined to the principal plane of a prism of refractive index $\mu$ are bent as if in the principal plane of a similar prism of index, $\mu'$, where

$$\mu' = \mu \frac{\cos k}{\cos h} = (\mu^2 - \sin^2 h)^{\frac{1}{2}} (1 - \sin^2 h)^{-\frac{1}{2}}$$ [186]

The minimum deviation, therefore, $D'_0$, measured in or projected onto the principal plane, of such rays is given by the equation,

$$\sin \frac{D'_0 + A}{2} = \mu \frac{\cos k}{\cos h} \sin \frac{A}{2}, \quad \text{- - - - - - - - - - -} \quad (5)$$

and the maximum, $D'_m$, by the equation,

$$\cos \left[(180^\circ - A) - D'_m\right] = \frac{\cos k}{\cos h} \sin (A - a), \quad \text{- - - - -} \quad (6)$$

[186] It may be interesting to note that this relation between the inclination of a ray to the principal plane of a prism and its deviation by that prism explains the curvature of spectrum lines as seen in an ordinary straight slit prism spectroscope.

in which $\alpha$ is the limiting value of the angle of refraction for the index $\mu'$, when

$$\mu' = \mu \frac{\cos k}{\cos h}.$$

The largest or limiting value of $h$ at which light can still pass through the prism obviously is determined by the equation,

$$\frac{D + A}{2} = 90°,$$

in which $D$ is the minimum deviation as projected on the principal plane.

In this case

$$\sin \frac{D + A}{2} = \mu \frac{\cos k}{\cos h} \sin \frac{A}{2} = 1. \qquad (7)$$

Therefore,

$$\frac{1}{\sin^2 \frac{A}{2}} = \mu^2 \frac{(1 - \sin^2 k)}{\cos^2 h} = \frac{\mu^2 - \sin^2 h}{\cos^2 h}$$

and

$$\cos h = \sqrt{\mu^2 - 1} \tan \frac{A}{2}.$$

Hence, when $A = 60°$, as between alternate sides of a hexagonal ice prism, or snowflake, the limiting value of $h$ for $\mu = 1.31$, is $60° 45'$, and when $A$ is $90°$, as between base and a side, $32° 12'$.

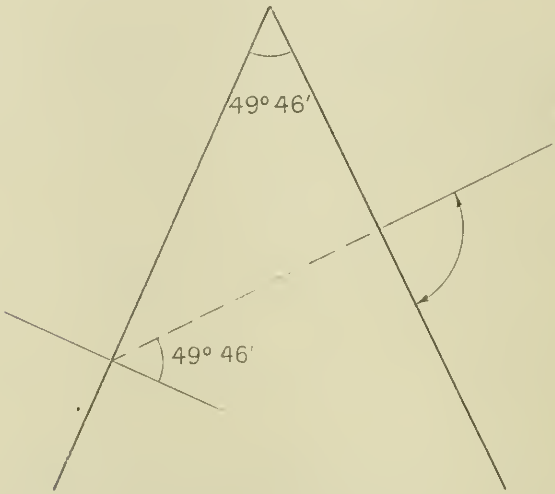
*Internal Total Reflection and Its Effect on the Passage of Light Through Ice Crystals.*—Since the limiting value of the "angle of incidence" is $90°$, and the refractive index of ice 1.31, it follows that total reflection of an internal ray occurs at the angle $\alpha$, given by the equation,

$$\sin 90° = 1.31 \sin \alpha = 1.31 \sin 49° 46'.$$

An internal ray, therefore, cannot leave an ice crystal if the angle it makes with the normal is greater than $49° 46'$. Hence, as is clear from Fig. 154, a ray of light in the principal plane, and also most rays out of it, will pass through an ice crystal between faces whose inclination is not greater than $49° 46'$ at all angles of incidence (measured on the base side of the normal) from $0°$ to $90°$. On the other hand, no light can pass through an ice crystal at any angle of incidence between planes whose inclination is greater than $2 \times 49° 46'$. In proof of this latter

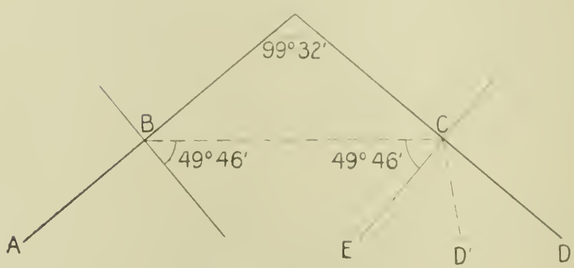
statement, let $AB$ (Fig. 155) be a ray grazing the side of a crystal whose angle of refraction is $99^{\circ} 32'$ and entering at $B$. It will reach the opposite face at $C$, and either pass out in the direction $CD$ or else suffer total reflection. But as $CD$ lies along the face of the crystal, it is clear that any decrease of the angle of incidence at $B$ from $90^{\circ}$, or increase of the inclination of the

FIG. 154.




Limiting angle of emission.

FIG. 155.




Limiting angle of transmission.

crystal faces to each other, each of which increases the angle $BCE$, causes total reflection at $C$, and thereby prevents transmission. Refracting angles intermediate between the above extremes obviously transmit light incident through an angular range less than $90^{\circ}$ and greater than $0^{\circ}$.

The largest angle of incidence clearly is 90°, and the smallest $i$, as determined by the equation,

$$\sin i = \mu \sin r = 1.31 \sin (A - 49° 26')$$

If, then, $A = 60°$, $i = 13° 54'$, giving a transmission range of 76° 6'; if $A = 90°$, $i = 58° 25'$, range 31° 35'; and similarly for other possible values of $A$.

*General Illumination of the Sky Through Ice Crystals.*—The deviation of a ray of light through refraction and $n$ internal reflections obviously is given by the equation,

$$D = i + i' + n\pi - \Sigma A,$$

in which $\Sigma A$ is the sum of the several angles passed by the ray in its course through the crystal. If these angles are all equal the equation becomes

$$D = i + i' + n\pi - (n + 1) A.$$

If, then, as frequently is the case, the ice crystal is a thick hexagonal disk floating horizontally, the position it oscillates about in falling, both angles passed by a once reflected ray will be 90°, provided the entering and emergent branches lie in the same plane, and the deviation will be

$$D = 2 i,$$

as readily seen in Fig. 156.

Hence, such crystals illuminate the sky at all distances from the sun out to 116° 50′. The effect, however, is not sufficiently striking ordinarily to arrest attention.

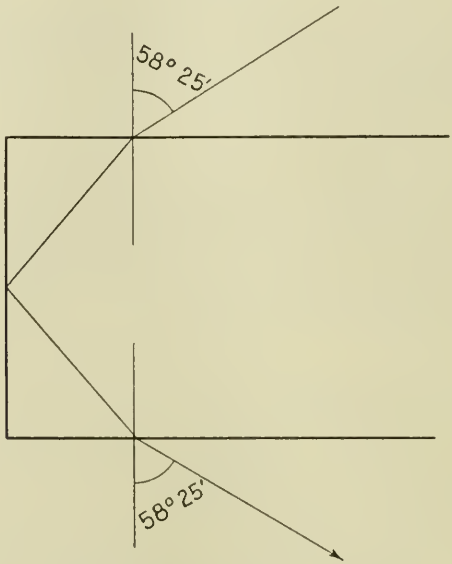
*Parhelia of* 22°.—Whenever the air through any depth or at any level contains innumerable hexagonal snow crystals with their sides vertical (the position about which relatively broad crystals oscillate) two colored bright spots, known as parhelia or sun dogs, appear at 22°, or more, from the sun, one to the right, the other to the left. Each bright spot obviously is in the direction of maximum light and, therefore, the direction of minimum refraction. When the refraction is in a principal plane, that is, as the sides of the crystal are vertical, when the sun is on the horizon, the angular distance, $D_0$, of each spot, also on the horizon, is given by the equation, derived from (3),

$$\sin \frac{D_0 + 60°}{2} = \mu \sin \frac{60°}{2}$$

For yellow light ($\mu = 1.31$), $D_0 = 21°\ 50'$; for red light ($\mu = 1.307$), $D_0\ 21°\ 34'$; and for violet ($\mu = 1.3117$), $D_0 = 22°\ 22'$. The order of the colors, therefore, counting from the sun, is red, yellow, etc., to violet, and the length or dispersion 48′ for a point source. For the sun, diameter 30′, the total length is 1° 18′, and width 30′.

Since the above are minimum angles, it follows that slight changes in either the inclination or orientation of the crystals causes rays of each color to come also from somewhat greater

FIG. 156.




Illumination of the sky by flat snow crystals.

distances from the sun. Hence, the only color thus produced that appears approximately pure is the darker portion of the red. Yellow and green are also moderately distinct, but blue, and especially violet, scarcely perceptible because of so much admixture of colors.

When the angular elevation of the sun is $h$, the distance, $D'$, in azimuth, of each of these parhelia from the sun is given by the equation, derived from (5),

$$\sin \frac{D' + 60°}{2} = \mu \frac{\cos k}{\cos h} \sin \frac{60°}{2}.$$

The angular distance, $\Delta_0$, measured on the arc of a great circle, between the sun and each of these parhelia, may be found from the right spherical triangle formed by the three sides: zenith to sun (compliment of $h$); zenith to mid point between sun and a parhelian: "mid point" to sun, $\frac{\Delta_0}{2}$. The angle thus formed at the zenith is $\frac{D'}{2}$, and the angle at the "mid point" 90°. Hence,

$$\sin \frac{\Delta_0}{2} - \cos h \sin \frac{D'}{2}$$

For $\mu = 1.31$ the following relations [187] exist between $h$, $D'$, and $\Delta_0$.

| $h$ | $D'$ | $\Delta_0$ |
|---|---|---|
| 0° | $D_0 = \Delta_0 =$ | 21° 50′ |
| 5° | 22° 2′ | 21° 56′ |
| 10° | 22° 30′ | 22° 10′ |
| 15° | 23° 20′ | 22° 32′ |
| 20° | 24° 34′ | 23° 4′ |
| 25° | 26° 22′ | 23° 50′ |
| 30° | 28° 44′ | 24° 49′ |
| 35° | 31° 56′ | 26° 3′ |
| 40° | 36° 20′ | 27° 38′ |
| 45° | 42° 30′ | 29° 42′ |
| 50° | 51° 30′ | 32° 26′ |
| 55° | 66° 2′ | 36° 26′ |
| 60° | 98° 48′ | 44° 38′ |
| 60°45′ | 120° 0′ | 50° 4′ |

All the above values pertain, as explained, to minimum deviation. But as the orientation of the crystals is fortuitous, it follows that all possible deviations from minimum to maximum will occur, and the parhelia, therefore, be drawn out into streaks the lengths of which depend upon their angular altitude.

The maximum deviation for refraction in a principal plane (for sun on the horizon when the crystal edges are vertical) is given by the equation, derived from (4),

$$\cos (180° - 60° - D_m) = \mu \sin (60° - 49° 26').$$

The value of the maximum deviation in azimuth, $D_m$, corresponding to the solar altitude, $h$, is given by equation (6), and the actual maximum, $\Delta_m$, by the equation,

$$\sin \frac{\Delta_m}{2} = \cos h \sin \frac{D'_m}{2}.$$

[187] Pernter-Exner, *Meteorologische Optik*, pp. 314, 315.

The following table [188] gives interesting relations between the quantities indicated:

| $h$ | $D_m$ | $\Delta_m$ | $\Delta_m - \Delta_0$ |
|---|---|---|---|
| 0° | 43° 28′ | 43° 28′ | 21° 38′ |
| 5° | 43° 38′ | 43° 26′ | |
| 10° | 44° 8′ | 43° 24′ | 21° 16′ |
| 15° | 44° 59′ | 43° 20′ | |
| 20° | 46° 15′ | 43° 18′ | 20° 18′ |
| 25° | 48° 0′ | 43° 16′ | |
| 30° | 50° 17′ | 43° 10′ | 18° 22′ |
| 35° | 53° 15′ | 43° 4′ | |
| 40° | 57° 9′ | 42° 58′ | 15° 22′ |
| 45° | 62° 28′ | 43° 2′ | |
| 50° | 68° 48′ | 43° 10′ | 10° 46′ |
| 55° | 81° 3′ | 43° 44′ | |
| 60° | 104° 54′ | 46° 44′ | 2° 6′ |
| 60°45′ | 120° 0′ | 50° 4′ | 0° 0′ |

From the computed values of $\Delta_m - \Delta_0$, fully supported by observations, it appears that when the angular elevation of a parhelion of 22° is moderate to small, 20° or less, it may extend over an arc, parallel to the horizon, of more than 20°. The end next the sun, produced by minimum deviation, is colored, beginning with red, through a short range. Similarly, the distal end, due to maximum deviation, is also colored, terminating with violet, though always too faint, perhaps, to be distinctly seen. Through the rest of its length the blending of the colors is quite complete, giving white, of course, as the result.

At greater altitudes the possible lengths of the parhelia of 22° become less and less, as shown by the table, though the color distribution remains the same.

*Halo of 22°.*—When the refracting edges of the ice crystals are vertical, as they tend to be in the case of relatively thin snowflakes falling through still air, parhelia are produced, as just explained. But, in general, these edges lie in all directions, especially at the windy cirrus level and when the crystals are of the short columnar type; and as refracted light reaches an observer in every plane through his eye and the sun (or moon) to which the refracting edges are approximately normal, it follows that the effect produced by fortuitously directed snow crystals must be more or less symmetrically distributed on all sides of the exciting luminary. There may, however, be a maximum brightness both

[188] Pernter-Exner, *Meteorologische Optik*, p. 317.

directly above and directly below the sun since ice needles tend to settle with their refracting edges horizontal.

As before, when the refracting angle is 60° and $\mu = 1.31$, corresponding to yellow light, $D_0 = 21° 50'$, and is independent of solar elevation. The inner portion of this, the most frequent and best known of all halos, is red, because light of that color is least refracted. Other colors follow, with increase of distance, in the regular spectral sequence, but with decrease of wave-length they so rapidly fade that even green is indistinct and blue seldom detected. This is owing to the variation in deviation caused by the tipping of the needles, as previously fully explained.

The brightest portion of the ring clearly is at the angle of minimum refraction from the sun. With increase of distance, light produced in this manner gradually fades (not all the crystals are ever simultaneously in position to give minimum refraction) until it ceases to be perceptible at 15° to 20° beyond the inner portion, or, say, 40° from the sun. On the other hand, no such light reaches the observer from places within the ring of maximum brightness, and, therefore, this portion of the sky is comparatively dark, except, and for an entirely different reason, to be explained later,[189] near the sun itself.

When the sun is within 10° of the horizon, the halo of 22°, and the parhelia of 22°, are practically superimposed. At greater altitudes they become distinctly separated, as per the accompanying table [190] for $\mu = 1.31$, in which $h$ = solar elevation, $\Delta_0$ = parhelic angular distance from the sun and $D_0$ = angular distance of halo from sun.

| $h$ | $\Delta_0 - D_0$ |
|---|---|
| 0° | 0° 0′ |
| 10° | 0° 20′ |
| 20° | 1° 14′ |
| 30° | 2° 59′ |
| 40° | 5° 48′ |
| 50° | 10° 36′ |
| 60° | 22° 48′ |
| 60°45′ | 28° 14′ |

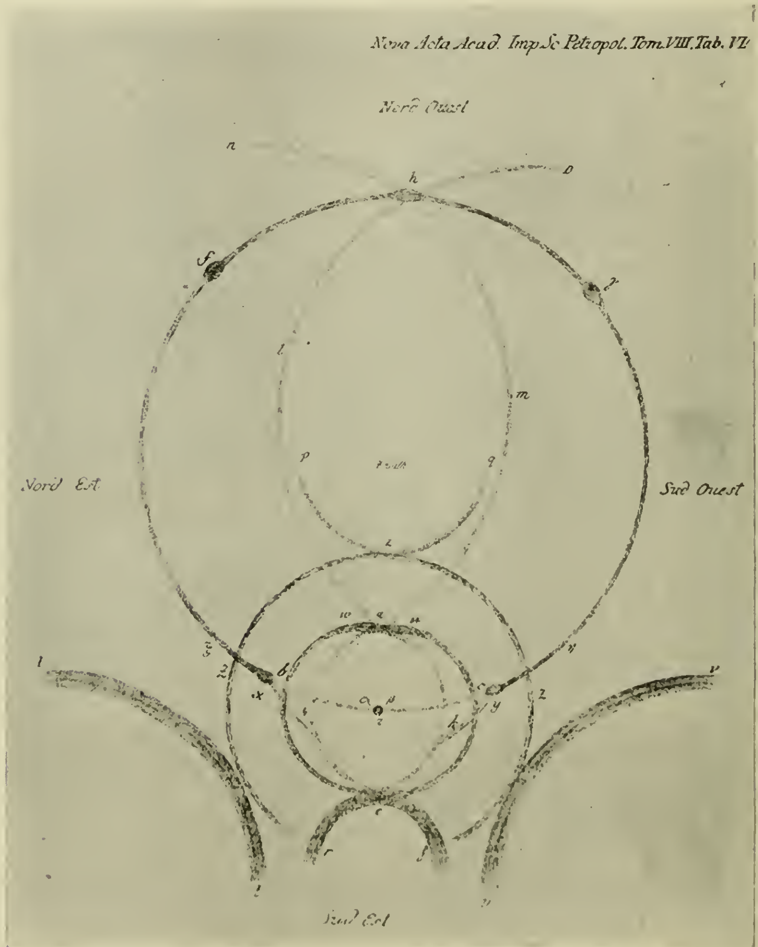
*Arcs of Lowitz, or Vertical Arcs of the 22° Parhelia.*—On rare occasions oblique extensions of the parhelia of 22°, concave towards the sun and with red inner borders, are seen, in addition to their horizontal tails, above described. These are known

[189] See chapter on diffraction.

[190] Pernter-Exner, *Meteorologische Optik*, p. 321.

as the arcs of Lowitz, after the astronomer who described them [101] as seen in the famous Petersburg halo complex (Fig. 157) of July 18, 1794. Their general explanation is simple, though exact

FIG. 157.




Petersburg halo of July 18, 1794.

computations of their outlines and of the relative intensities of their parts for different altitudes of the sun are rather tedious.

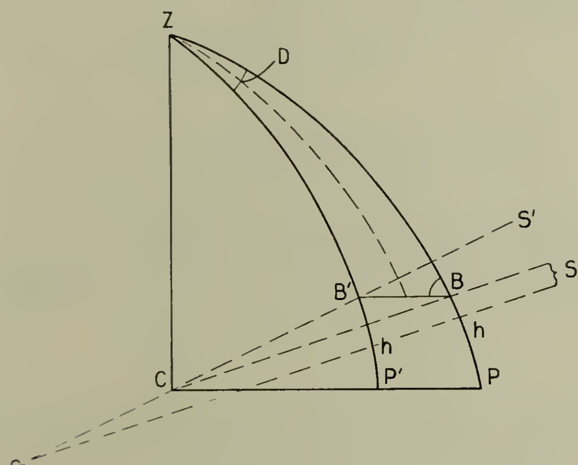
[101] *Nova acta Acad. Petropol.*, 8, 1794, p. 384.

As already explained, parhelia and their horizontal extensions are produced by ice crystals whose principal axes are vertical, the former by those set to minimum refraction, and the latter by crystals turned more or less from this unique position.

When, however, the principal axes oscillate about the vertical, as they obviously do in the case of snowflakes, the arcs of Lowitz, or obliquely vertical extensions of the parhelia of 22°, necessarily are produced, though rarely seen, because of the diffusion of their light in the midst of a general glare, as will be explained below.

Consider, first, for simplicity, the doubly special case in

FIG. 158.




Formation of the arc of Lowitz, crystals vibrating in solar vertical.

which the sun is on the horizon and the principal axes of the crystal oscillate in a vertical plane passing through the sun. Let $C$ (Fig. 158) be the position of an ice crystal whose principal axis is in the direction $CZ$. Let an observer be at $O$ and let the incident ray, $SC$, lying between $Z$ and $P$ make the angle $h$ with the principal plane, $CP$. On emerging this ray, in its new direction, $S'O$, has the same inclination as formerly to the axis. Hence, $SC$ and $S'C$ may be regarded as elements of a right cone of vertex $C$ and axis $CZ$, and as the plane $CZS$ is vertical, if $S$ is on the horizon, as seen from $O$, the element $CS$ (lowest element), being parallel to $OS$, owing to the great distance of $S$, will lie in

a plane tangent to the cone and parallel to the plane of the horizon, while every other element, such as $CS'$, will lie above it. $S'$, therefore, the apparent position of $S$ due to refraction of the ray $SC$ by the ice crystal at $C$ is above this plane and, also, as seen from $O$ at the same angular distance above the horizon. Similarly, when the axis of the crystal is tipped beyond the vertical in the opposite direction, $S'$ drops below the horizon.

Further, let $ZP$ and $ZP'$ be arcs of great circles intersecting $SC$ and $S'C$ at $B$ and $B'$, respectively. Then the projection of the deviation $SCS'$, or $SOS'$, on the principal plane is given by the angle $D$ between these arcs, and on bisecting $D$, thus dividing $ZBB'$ into two equal right spherical triangles, and putting $BB' = \Delta$, it is obvious that

$$\sin\frac{\Delta}{2} = \sin\frac{D}{2}\cos h \text{ - - - - - - - - - - - - - - } (1)$$

and

$$\cot B = \tan\frac{D}{2}\sin h \text{ - - - - - - - - - - - - - } (2)$$

Clearly, then, the locus of $S'$ is given when the arc $BB'$ is known in terms of the angle $B$.

On eliminating $h$ from the above equations, it appears that

$$\cot^2 B = \tan^2\frac{D}{2}\cos^2\frac{\Delta}{2} - \sin^2\frac{\Delta}{2} \text{ - - - - - - - - - - - } (3)$$

Hence, that either $\Delta$ or $B$ may be found when the other is given, it remains only to express $\tan^2\frac{D}{2}$ in terms of a function or functions of $\Delta$.

But from (7), (p. 613),

$$\sin^2\frac{D+A}{2} = \mu^2\frac{\cos^2 k}{\cos^2 h}\sin^2\frac{A}{2}$$

$$= \left\{1 + (\mu^2 - 1)\sec^2 h\right\}\sin^2\frac{A}{2}.$$

Also from (3), (p. 610),

$$\mu^2 = \frac{\sin^2\dfrac{D_0 + A}{2}}{\sin^2\dfrac{A}{2}}$$

and from (1),

$$\sec^2 h = \frac{\sin^2 \frac{D}{2}}{\sin^2 \frac{\Delta}{2}}.$$

Hence,

$$\frac{\sin^2 \frac{D+A}{2} - \sin^2 \frac{A}{2}}{\sin^2 \frac{A}{2}} = \frac{\sin^2 \frac{D_0+A}{2} - \sin^2 \frac{A}{2}}{\sin^2 \frac{A}{2}} \times \frac{\sin^2 \frac{D}{2}}{\sin^2 \frac{\Delta}{2}}$$

or

$$\sin^2 \frac{\Delta}{2} \sin\left(\frac{D}{2} + A\right) \sin \frac{D}{2} = \sin^2 \frac{D}{2} \sin\left(\frac{D_0}{2} + A\right) \sin \frac{D^2}{2}.$$

Dividing by $\cos \frac{D}{2} \cos A$,

$$\sin^2 \frac{\Delta}{2} \tan \frac{D}{2} + \sin^2 \frac{\Delta}{2} \tan A = \frac{\sin\left(\frac{D_0}{2} + A\right) \sin \frac{D_0}{2} \tan \frac{D}{2}}{\cos A}$$

$$= \tfrac{1}{2}\left\{1 - \frac{\cos(D_0 + A)}{\cos A} \tan \frac{D}{2}\right\}$$

Putting

$$\frac{\cos D_0 + A}{\cos A} = \cos\beta = \cos 73^\circ\ 30'$$

$$\tan \frac{D}{2} = \frac{2 \tan A \sin^2 \frac{\Delta}{2}}{\cos\Delta - \cos\beta} \quad \text{- - - - - - - - - - - - - (4)}$$

On using this value of $\tan \frac{D}{2}$ (3) reduces to

$$\cot B = \frac{\sin \frac{\Delta}{2} \sqrt{4 \sin^2 \frac{\Delta}{2} \cos^2 \frac{\Delta}{2} \tan^2 A - (\cos\Delta - \cos\beta)^2}}{\cos\Delta - \cos\beta} \quad \text{- - (5)}$$

From (5) $B$ is readily computed for any assumed value of $\Delta$, as is also $D$ form (4). Further, $h$ can be found from (1) when $\Delta$ and $D$ are known, or from (2) when $B$ and $D$ are known.

The following table, copied from Pernter-Exner,[192] as are

[192] *l. c.*, p. 327.

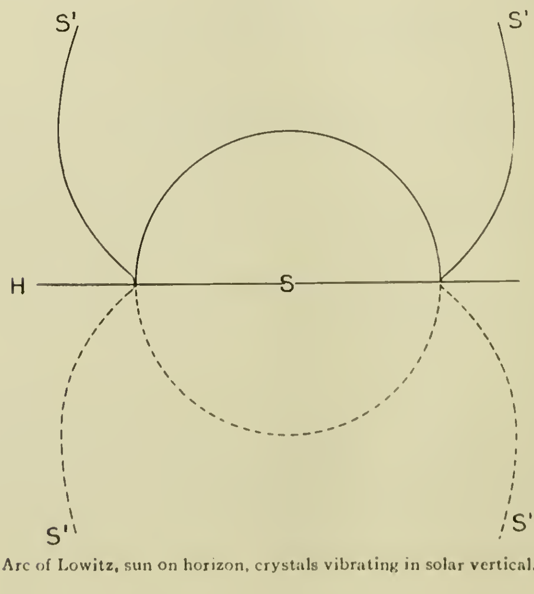
most of the above equations, gives data for drawing the locus of $S'$ when the sun is on the horizon.

Since the value of $\Delta$ in this table increases with $\mu$, other things being equal, it follows that these arcs must be colored and that their inner borders must be red, as stated.

| $h$ | $\Delta$ | $B$ |
|---|---|---|
| 0° | 21° 50′ | 90° 0′ |
| 5° | 21° 55′ | 89° 5′ |
| 10° | 22° 10′ | 88° 1′ |
| 15° | 22° 38′ | 86° 54′ |
| 20° | 23° 04′ | 85° 45′ |
| 25° | 23° 51′ | 84° 19′ |
| 30° | 24° 49′ | 82° 38′ |
| 35° | 26° 3′ | 80° 38′ |
| 40° | 27° 38′ | 78° 5′ |
| 45° | 29° 42′ | 74° 36′ |
| 50° | 32° 26′ | 69° 43′ |
| 55° | 36° 26′ | 61° 58′ |
| 60° | 44° 38′ | 44° 41′ |
| 60°45′ | 50° 4′ | 33° 29′ |

This table is graphically represented by Fig. 159, in which the circle is the 22° halo, $HH$ the horizon, $S$ the sun and $S'S'$ the curve in question, dotted below the horizon where, of course,

FIG. 159.

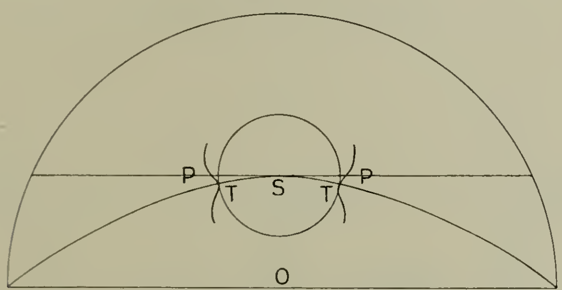



Arc of Lowitz, sun on horizon, crystals vibrating in solar vertical.

like the under portion of the circle, it is invisible, except from a suitable elevation.

Obviously, the optical effect is independent of the manner by which the inclination of the principal axis of the crystal to the incident ray is produced, and, therefore, crystals tilted in the vertical plane through the sun to an angle, $E + h$, to the plane of the horizon give the same result, if $E$ is the solar elevation, as do crystals tilted to only the angle $h$ in this plane when the sun is on the horizon. The points of contact with the halo of 22°, being due to crystals whose principal axes are normal to the incident rays, lie, therefore, at equal altitudes on opposite sides of the halo and in a plane that passes through the sun. Consequently, the angular altitude of these points is less than that of the sun, except when the latter is on the horizon. If, as before, $E$ is the elevation of the sun and $E'$ that of the points of contact in question, then, from the right spherical triangle formed by the radius

FIG. 160.




Arcs of Lowitz, elevation of sun 40°, crystals vibrating in solar vertical.

of the halo and the zenith distances of the sun and point of contact, respectively,

$$\cos (90° - E') = \cos (90° - E) \cos 21° 50'.$$

Fig. 160 represents, approximately, the outline of the bright band produced in this manner when the elevation of the sun is 40°; making that of the points of contact 36° 38′. $O$ is the position of the observer, $S$ the centre of the halo of 22°, $PP$ parhelia of 22°, $TT$ the points of tangency to this circle of the arcs of Lowitz, $PT$ $PT$. In order that the arc may reach the halo, the tilt of the crystal must at least equal the elevation of the sun, and

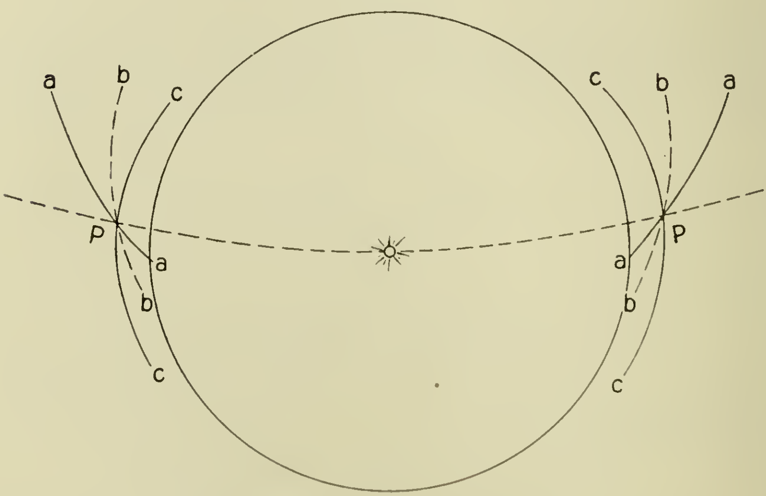
no portion of the lower branch (part below point of tangency) is given unless the tilt is greater than this elevation. Hence, if the extent of the tilting of snow crystals is less, in the great majority of cases, than 30°, as it probably is, only the upper branch is likely to be produced when the sun is 30° or more above the horizon.

Consider, now, the effect of the vibration of the principal axis in a vertical plane at right angles to the vertical plane through the sun. Let $E$ be the elevation of the sun and $i$ the inclination of the principal axis to the vertical, then the angle $h$ between the incident ray and principal plane is given by the equation,

$$\sin h = \sin (90° - i) \sin E.$$

Let $E = 30°$, and $i = 20°$. Then the angular distance from the sun to a parhelion of 22° is 24° 49′, or say 3° from the halo

FIG. 161.




Arcs of Lowitz, crystals vibrating at random.

of 22°. Also $h = 28°\ 1'$, and the corresponding distance of image from halo is about 2° 40′, at approximately 20°, measured from centre of halo, above or below the parhelion, owing to direction of tip.

Vibrations of the principal axis in intermediate planes give images, of course, in intermediate positions, so that the total

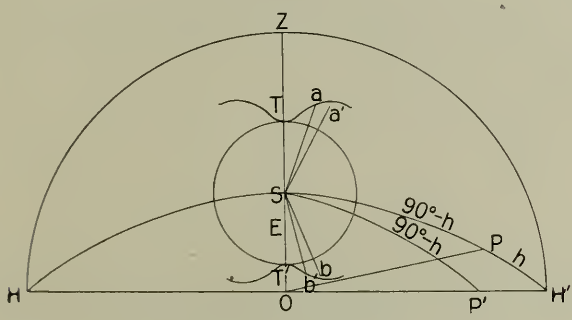
effect, when the elevation of the sun is 30°, may be somewhat as represented in Fig. 161, in which tilting is supposed to be restricted to 30° and less from the vertical.

In this Figure, *PP* are the parhelia of 22°, *aa, bb,* and *cc* the outlines of the images corresponding to minimum refraction when the principal axis is oscillated in a vertical plane through the sun, true tangent arcs; at 45°, roughly interpolated, to this sun plane; and at 90° to it, respectively.

It will be noticed that this light, nearly always too faint to be distinguished from the general glare, would be more concentrated, if the orientation of the ice crystals were fortuitous, which, presumably, often is the case, and consequently brighter below the parhelia than above them. Hence, because of limited tilting, as above explained, and because of the greater concentration of light in its lower branches, this halo, whenever seen at all, appears as short arcs including the parhelia and extending mainly below them.

*Tangent Arcs of the Halo of 22°.*—Obviously, when the sun is on the horizon, ice crystals whose principal axes lie or oscillate

FIG. 162.



Tangent arcs of the halo of 22°.

in horizontal planes must produce the same optical effects above and below (theoretically) the halo of 22° that are produced on its sides, as above explained, by crystals whose principal axes oscillate in the vertical plane through the sun. Each set of curves might properly be called tangent arcs of the halo of 22°, but as a matter of fact only those well-known and fairly common arcs that occur above and below the circular halo are so designated.

Similarly, when the elevation of the sun is *E*, arcs identical

with those just described and tangent to the halo at its highest and lowest points, as shown in Fig. 162, are formed by crystals whose principal axes oscillate in planes normal to the solar vertical and inclined at the angle $E$ to the plane of the horizon.

But ice spicules or needles tend to float with their principal axes horizontal. Hence, it is necessary carefully to determine the optical effects of crystals in this particular position, as may be done by noting the transformations of the tangent arcs as the crystals are so turned as to carry their principal axes from the inclined to the horizontal plane.

Let, then, the principal axis of an ice needle lie parallel to $OP$ (Fig. 162) in which $O$ is the position of the observer, $HSH'$ the inclined plane and $S$ the sun at elevation $E$. Let $h$ be the inclination of the principal axis to the incident radiation and let $a$ or $b$ be the position of the resulting image. Now, let the crystal, as suggested above, be so turned as to carry its axis from an inclined to a horizontal position, and in such manner as to keep *constant* the angle between the principal axis and the direction of the incident ray. That is, change the direction of the axis from parallel to $OP$ to parallel to $OP'$, with $SP = SP'$. Under these conditions the refracted ray will turn precisely as does the principal axis. Hence, if $a'$ and $b'$ are the new positions of $a$ and $b$, the angle $aSa' = bSb' = PSP'$.

But from the right spherical triangle $OSP'$

$$\cos OSP' = \sin PSP' = \tan E \cot SP' = \tan E \tan h,$$

and

$$aSa' = bSb' \text{ arc } \sin \tan E \tan h.$$

Since the points of tangency of the "tangent arcs" under consideration are 90° from the corresponding points of the similar "arcs of Lowitz," it follows that the angle $B$ of Fig. 158 and table on page 624 equals $TSa$ (Fig. 162).

Hence,

$$\left. \begin{matrix} TSa' \\ T'Sb' \end{matrix} \right\} \equiv S = B \pm \text{ arc } \sin \tan E \tan h$$

The following table, adapted from Pernter-Exner, "Meteorologische Optik," pp. 338–339, gives the necessary data for accurately constructing tangent arcs corresponding to different solar elevations:

*Values of Angle S.*

| E | | 5° | | 10°55′ | | 15° | | 20° | | 25°2′ | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| h | Δ | Top | Bottom | Top | Bottom | Top | Bottom | Top | Bottom | Top | Bottom |
| 0° | 21°50′ | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0′ |
| 5 | 21 55 | 1 21 | 0 29 | 1 50 | 0 0 | 2 16 | −0 26 | 2 45 | −0 55 | 3 16 | − 1 26 |
| 10 | 22 10 | 2 52 | 1 06 | 3 56 | 0 02 | 4 42 | −0 44 | 5 40 | −1 42 | 6 42 | − 2 44 |
| 15 | 22 38 | 4 27 | 1 45 | 6 04 | 0 08 | 7 13 | −1 01 | 8 42 | −2 30 | 10 17 | − 4 05 |
| 20 | 23 04 | 6 15 | 2 35 | 8 27 | 0 25 | 10 01 | −1 11 | 12 02 | −3 12 | 14 12 | − 5 22 |
| 25 | 23 51 | 8 01 | 3 21 | 10 51 | 0 31 | 12 52 | −1 30 | 15 27 | −4 05 | 18 16 | − 6 54 |
| 30 | 24 49 | 10 16 | 4 28 | 13 46 | 0 58 | 16 16 | −1 32 | 19 30 | −4 46 | 23 01 | − 8 17 |
| 35 | 26 03 | 12 53 | 5 51 | 17 08 | 1 36 | 20 11 | −1 27 | 24 08 | −5 24 | 28 28 | − 9 44 |
| 40 | 27 38 | 16 08 | 7 42 | 21 14 | 2 36 | 24 55 | −1 05 | 29 42 | −5 52 | 34 59 | −11 19 |
| 45 | 29 42 | 20 25 | 10 23 | 26 31 | 4 17 | 30 57 | −0 09 | 36 45 | −5 57 | 43 16 | −12 28 |
| 50 | 32 26 | 26 16 | 14 18 | 33 34 | 7 00 | 38 55 | 1 39 | 46 10 | −5 26 | 54 07 | −13 33 |
| 55 | 36 26 | 35 13 | 20 51 | 44 02 | 12 02 | 50 32 | 5 32 | 59 21 | −3 17 | 69 53 | −13 49 |
| 60 | 44 38 | 54 02 | 36 36 | 64 50 | 25 48 | 72 58 | 17 40 | 84 25 | 6 13 | 99 19 | − 8 41 |
| 60°45′ | 50 04 | 65 30 | 47 32 | 76 40 | 36 22 | 85 06 | 27 56 | 97 04 | 15 28 | 113 02 | 0 0 |

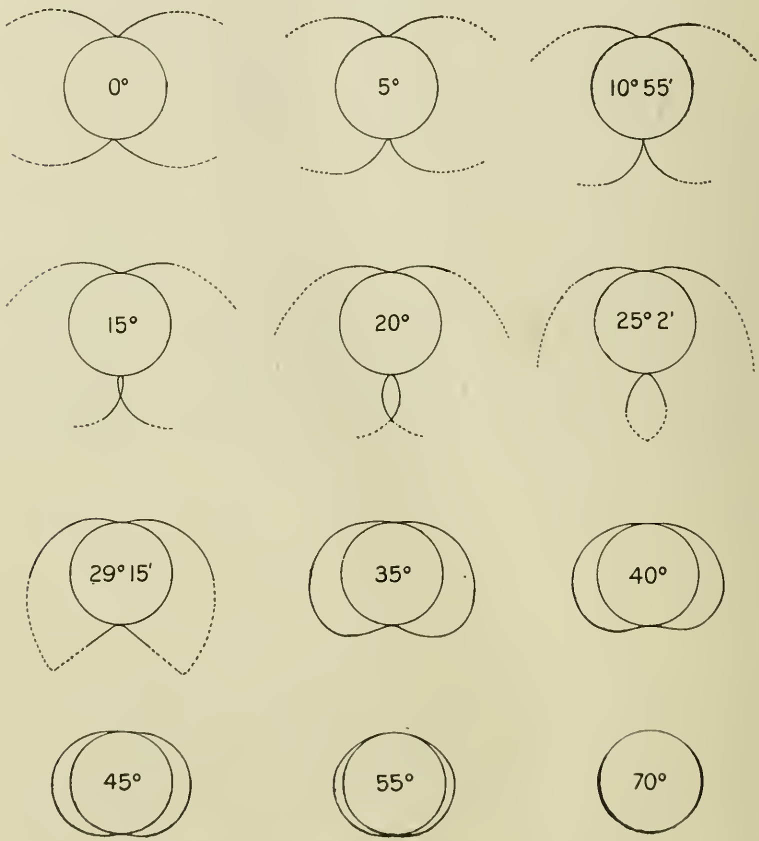
| E | | 29°15′ | | 35° | | 40° | | 45° | | 50° | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| h | Δ | Top | Bottom | Top | Bottom | Top | Bottom | Top | Bottom | Top | Bottom |
| 0° | 21°50′ | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0, | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0′ |
| 5 | 21 55 | 3 44 | − 1 54 | 4 26 | − 2 36 | 5 08 | − 3 18 | 5 56 | − 4 06 | 6 54 | − 5 04 |
| 10 | 22 10 | 7 39 | − 3 41 | 9 04 | − 5 06 | 10 30 | − 6 32 | 12 09 | − 8 11 | 14 07 | −10 09 |
| 15 | 22 38 | 11 54 | − 5 32 | 13 51 | − 7 43 | 16 06 | − 9 54 | 18 39 | −12 27 | 21 44 | −15 32 |
| 20 | 23 04 | 16 11 | − 7 21 | 19 11 | −10 21 | 22 12 | −13 22 | 25 46 | −16 56 | 20 08 | −21 18 |
| 25 | 23 51 | 20 49 | − 9 27 | 24 45 | −13 23 | 28 43 | −17 21 | 33 29 | −22 07 | 39 26 | −28 04 |
| 30 | 24 49 | 26 14 | −11 30 | 31 12 | −16 28 | 36 20 | −21 36 | 42 38 | −27 54 | 50 50 | −36 06 |
| 35 | 26 03 | 32 27 | −13 43 | 38 43 | −19 59 | 45 21 | −26 37 | 53 48 | −35 04 | 65 55 | −47 11 |
| 40 | 27 38 | 39 57 | −16 07 | 47 54 | −24 04 | 56 40 | −32 50 | 68 57 | −45 07 | 101 55 | −78 05 |
| 45 | 29 42 | 49 27 | −18 39 | 59 50 | −29 02 | 72 26 | −41 38 | 105 24 | −74 36 | ..... | ....... |
| 50 | 32 26 | 62 09 | −21 35 | 76 50 | −36 16 | 110 17 | −69 43 | ..... | ....... | ..... | ....... |
| 55 | 36 26 | 81 09 | −25 07 | 118 02 | −61 58 | ..... | ....... | ..... | ....... | ..... | ....... |
| 60 | 44 38 | 121 15 | −30 37 | ..... | ....... | ..... | ....... | ..... | ....... | ..... | ....... |
| 60°45′ | 50 04 | 146 31 | −33 29 | ..... | ....... | ..... | ....... | ..... | ....... | ..... | ....... |

| E | | 55° | | 60° | | 70° | | 80° | |
|---|---|---|---|---|---|---|---|---|---|
| h | Δ | Top | Bottom | Top | Bottom | Top | Bottom | Top | Bottom |
| 0° | 21°50′ | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0′ | 0° 0′ | 0 ° 0′ | 0° 0′ |
| 5 | 21 55 | 8 06 | − 6 16 | 9 38 | − 7 48 | 14 50 | −13 00 | 30 40 | −28 50 |
| 10 | 22 10 | 16 34 | −12 36 | 19 46 | −15 48 | 30 58 | −27 00 | 91 59 | −88 01 |
| 15 | 22 38 | 25 36 | −19 28 | 30 45 | −24 33 | 50 31 | −44 19 | .... | ....... |
| 20 | 23 04 | 35 45 | −26 57 | 41 31 | −34 41 | 94 25 | −85 35 | .... | ....... |
| 25 | 23 51 | 47 26 | −36 01 | 59 34 | −48 12 | .... | ....... | .... | ....... |
| 30 | 24 49 | 62 54 | −48 07 | 97 22 | −82 38 | .... | ....... | .... | ....... |
| 35 | 26 03 | 99 22 | −80 38 | .... | ....... | .... | ....... | .... | ....... |
| 40 | 27 38 | .... | ....... | .... | ....... | .... | ....... | .... | ....... |
| 45 | 29 42 | .... | ....... | .... | ....... | .... | ....... | .... | ....... |
| 50 | 32 26 | .... | ....... | .... | ....... | .... | ....... | .... | ....... |
| 55 | 36 26 | .... | ....... | .... | ....... | .... | ....... | .... | ....... |
| 60 | 44 38 | .... | ....... | .... | ....... | .... | ....... | .... | ....... |
| 60°45′ | 50 04 | .... | ....... | .... | ....... | .... | ....... | .... | ....... |

The upper and lower tangent arcs change with elevation, $E$, of the sun, as indicated by the table and shown in Fig. 163, copied from Pernter-Exner, "Meteorologische Optik." Portions below the natural horizon can only be seen from sufficient heights.

With increase of elevation of the sun from the horizon the branches of the lower tangent arc draw closer together; become

FIG. 163.




Upper and lower tangent arcs at solar elevations indicated.

pointed; cross, forming a loop; then open out and turn up where they merge with the drooped branches of the upper tangent arc and thus form an enclosing curve, with red inner border, which, at first, when the elevation is 30° to 35°, is bagged below; then, when the elevation is 50° to 60°, approximately elliptical; and,

finally, at elevations of 75° and more, indistinguishably merged with the circular halo. The brightest portions of these arcs are at and near the points of tangency. Hence, when the solar elevation is 35° to 45° the lower arc, if visible over only its brightest part, appears as an inferior tangent arc, which, indeed, it is, circular, perhaps, and limited to, say, 10° to 20°, which, in reality, it is not.

*Frequency of Horizontal and Rarity of Vertical Tangent Arcs.*—Since the theory of the formation of the horizontal (upper and lower) tangent arcs of the halo of 22° is identical with that of the vertical (arcs of Lowitz), it will be interesting to consider why, though the former is fairly common, the latter is extremely rare. Obviously this must somehow be connected with the attitudes, which radically do differ, of the principal axes of the ice crystals that produce them. The horizontal tangent arcs are produced, as already explained, by crystals whose principal axes are horizontal, and, therefore, by columnar crystals, since these and these alone tend to assume this as an attitude of maximum frequency and thus produce a corresponding concentration of light.

The vertical tangent arcs (arcs of Lowitz), on the other hand, being produced by crystals whose principal axes oscillate in that particular vertical plane that passes through the sun nearly always are too faint to be seen, because, in part, this unique attitude can only rarely be assumed by any considerable proportion of the crystals present. Even the combined effect of the crystals in all vertical planes is seldom noticed because, as explained, of its width and consequent faint nebulosity.

Another factor that probably contributes to the contrast between the frequencies of occurrence of the two types of tangent arcs is the fact that columnar crystals whose principal axes tend to lie horizontal probably are far more effective as refractors, or halo producers, than are the tabular crystals whose principal axes tend to stand vertical. This is because the tabular crystals are so filled with air spaces or other heterogeneities, as shown by their photomicrographs, that anything like regular transmission of light through them from edge to edge is hardly possible. The columns, on the other hand, appear to be more nearly homogeneous and, consequently, much more effective as refractors. This is partially confirmed by the fact that halos often are

seen close at hand in polar regions when the air is filled with ice needles, and rarely if ever seen in ordinary snowstorms consisting essentially of tabular crystals.

The greater efficiency (presumably), then, of the columnar crystal, whose principal axis tends to lie horizontally, as a refractor, over that of the tabular crystal whose principal axis tends to stand vertical, together with the further fact that the orientation of the vertical plane of oscillation must nearly always be fortuitous, seems to explain why the horizontal tangent arc of the halo of 22° is so frequently seen and the vertical so rarely.

It should be remembered, however, that, in apparent contradiction of the above statements concerning the maximum frequency attitudes of the principal axes of ice crystals, there are two special types of columnar crystals whose principal axes tend to stand vertical; namely, those that are shorter than broad (tabular when much shorter than broad), and those that have tabular caps. Perhaps, therefore, all halo phenomena are due essentially to columnar and very little to tabular crystals.

*Parhelia of 46°*—Since the flat ends of columnar snow crystals and the flat sides of tabular ones both are at right angles to the sides, it follows that optical phenomena must occur that are produced by refraction at such angles, analogous to those already explained for the 60° angle.

Let, then, the 90° intersection be vertical, as it is, more or less, in the case especially of columnar crystals, and let the orientation be that of minimum refraction. If, now, the sun is on the horizon, the distance from it to either of its refraction images, also on the horizon, corresponding to the angle in question, are given by substitution in the general equation,

$$\sin\frac{D_0 + A}{2} = \mu \sin\frac{A}{2}.$$

On putting $\mu = 1.31$, this becomes

$$\sin\left(\frac{D_0}{2} + 45°\right) = 1.31 \sin 45°,$$

from which $D_0 = 45° \ 44'$.

Hence, these images are known as the parhelia of 46°.

With increase of elevation of the sun the inclination, $h$, of the incident ray to the vertical face of the crystal is equally increased, as is also the elevations of the images, as we know from previous

considerations. Hence the positions of the parhelia of 46° corresponding to different elevations of the sun may be found in the same manner as those of 22°. On substituting, then, in the equation,

$$\sin\frac{D'+A}{2}=\mu\frac{\cos k}{\cos h}\sin\frac{A}{2},$$

in which $\sin h=\mu \sin k$, the proper values of $\mu$ and $A$, namely 1.31 and 90°, respectively, and also computing the corresponding values of $\Delta'_0$, one obtains the following table:

| $h$ | $D'_0$ | $\Delta'_0$ |
|---|---|---|
| 0° | 45° 44′ | 45° 44′ |
| 5° | 46° 11′ | 46° 0′ |
| 10° | 47° 36′ | 46° 50′ |
| 15° | 50° 08′ | 48° 18′ |
| 20° | 54° 08′ | 50° 38′ |
| 25° | 60° 48′ | 54° 36′ |
| 30° | 72° 48′ | 61° 52′ |
| 32°12′ | 90° 0′ | 73° 30′ |

These parhelia, like those of 22°, also trail off parallel to the horizon, for crystals whose attitudes differ somewhat from that of minimum refraction. Such trails, however, necessarily are very faint, and perhaps never observed. In fact, these parhelia themselves are only rarely seen.

*Halo of 46°.*—Since, as just explained, the image, $S_1$ (Fig. 164), of the sun produced in the principal plane of a 90° refracting angle of an ice crystal, as seen by the observer, $O_1$, is 45° 44′ from the sun, $S$, itself ($\mu=1.31$), it follows that when such crystals are very abundant and set at random in all directions the innumerable images so produced must together assume the shape of a ring about the sun of radius 45° 44′. This is the well-known, though not very common, halo of 46°.

Whenever at all conspicuous, this halo also shows colors (red being nearest the sun) which, because of the greater dispersion produced by the angle of 90° than by the angle of 60°, are more widely separated than in the halo of 22°. Hence, it likewise has the greater width of the two—about 2° 36′, corresponding to the diameter of the sun, 30′, plus the dispersion, that is, to $30'+D_v$, $(\mu=1.317)-D_r$, $(\mu=1.307)=30'+47°\ 16'-45°\ 10'=2°\ 36'$.

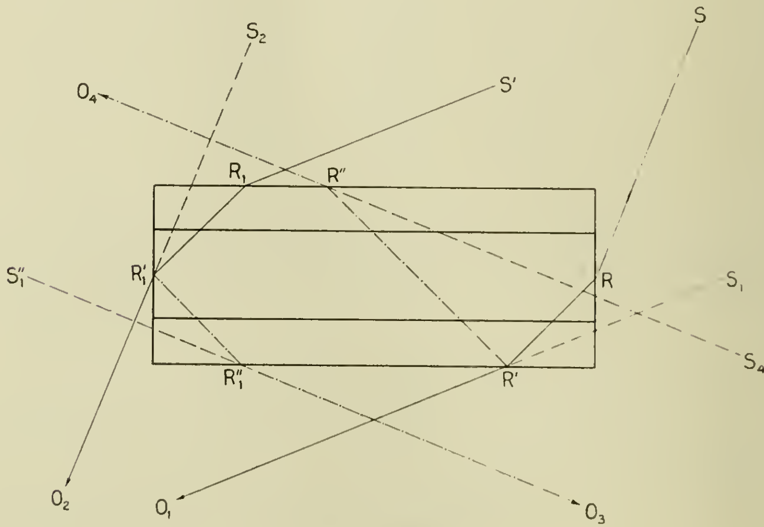
In addition to the colored ring, there is also a broad outer band of diffuse white light corresponding to all refractions other

than the minimum, but it is too faint and too uniformily distributed to be conspicuous, or, perhaps, unmistakably seen even when carefully looked for.

*Halo of 90°.*—Occasionally, a faint white halo, sometimes called the halo of Hevelius, is seen at 90° from the sun.

Several explanations of this halo have been suggested, but none gives it the right distance from the sun or is otherwise satisfactory. The following simple theory of its formation, therefore, is offered, based on the presence of fortuitously directed columnar crystals—short columns. Let a ray of whatever

Fig. 164.




Formation of halo of 46°.

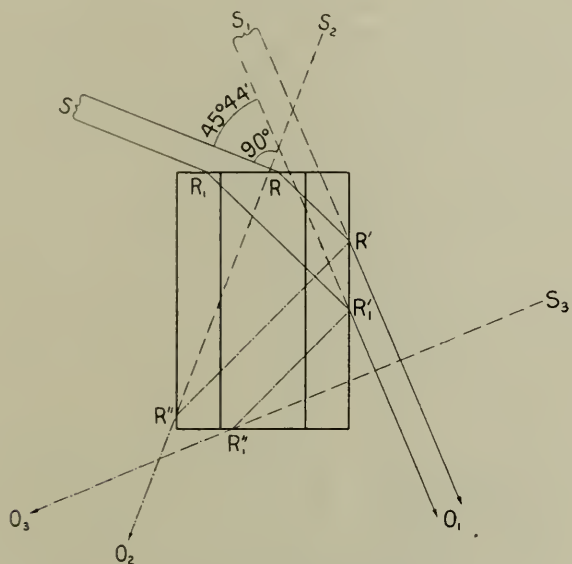
wave-length be incident at $R$, say (Fig. 165), on the flat end of a columnar crystal in the direction appropriate to *minimum refraction,* and let most of that portion of it reflected at $R'$ emerge from the opposite face at $R''$. The resulting image, $S_2$, seen by an observer at $O_2$, clearly is 90° from $S$. And since this direction holds for the more concentrated (minimum refracted) portion of every color, it follows that the resulting 90° halo must be white. It also must be more sharply defined on the side away from than on the side next to the sun.

*Bouguer's Halo, White Halo of 136°.*—Rays entering a hori-

zontal crystal face at $R_1$ and emerging at $R''_1$ (Figs. 164 and 165) clearly must produce a faint white image at about $135° 44'$ ($\mu = 1.31$) from the sun, and a cloud of such horizontal crystals a white halo of outer radius $44° 16'$ and inner radius much less about the antisolar point as a centre. Perhaps this is the Bouguer's halo, or false white rainbow, the theory of which has been considered obscure.

*Circumzenithal Arc.*—Occasionally, an arc of, perhaps, 90°, having its centre at the zenith, and, therefore, known as the cir-

FIG. 165.




Formation of the white halo of 90°.

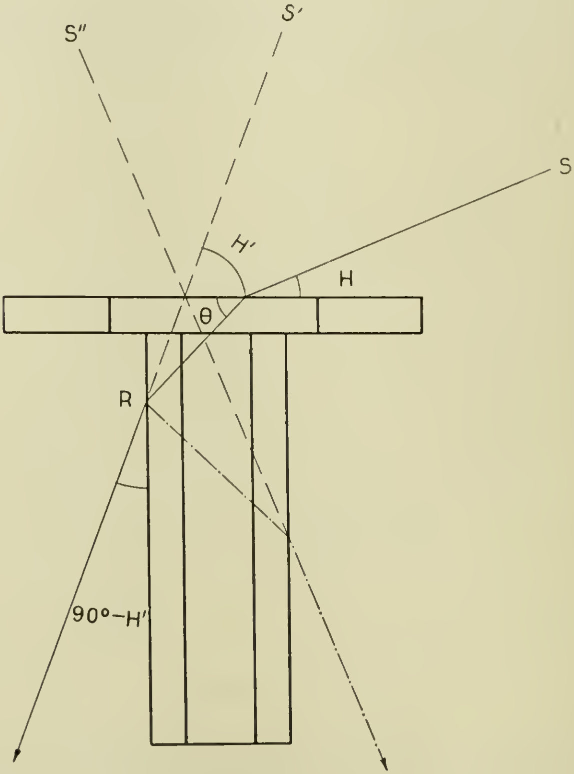
cumzenithal arc, is seen some 46°, or a little more, above the sun. It generally lasts only a few minutes, about five on the average, but during that time often is so brilliantly colored, especially along that portion nearest the sun—red on the outside, to violet inclusive—as to be mistaken by persons unfamiliar with it for an exceptionally bright rainbow. It occurs most frequently when the altitude of the sun is about 20° and at times when the parhelia of 22° are conspicuous. Presumably, therefore, when the principal axes of a large portion of the crystals are practically vertical. That is, when the snow crystals are largely columnar

with tabular caps, a moderately common form,[193] as outlined in Fig. 166.

The explanation of this halo, as of many others, was first given by Bravais,[194] and is very simple.

In still or steadily flowing air the type of crystals assumed

Fig. 166.




Formation of circumzenithal arc.

will keep their principal axes substantially vertical. Let, then, $H$ (Fig. 166) be the altitude of the sun above the horizon, and also the angle between the incident ray and the upper horizontal surface of the crystal; let $\theta$ be the angle between this surface and

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[193] Bentley, *Monthly Weather Review*, 30, p. 609, 1902.

[194] Mémoire sur les halos, *Journal de l'École polytechnique*, 31me cahier, 1845.

the refracted ray, and let $H'$ be the altitude of the solar image produced by the 90° prism.

Hence,

$$\cos H = \mu \cos \theta,$$

and

$$\sin H' = \mu \sin \theta = \sqrt{\mu^2 - \cos^2 H}.$$

As previously explained, the angles between a principal plane (plane normal to the refracting edge) and incident and emergent rays are equal. Therefore, since the position of the image is altered by rotation of the crystal about its principal axis while its altitude remains unchanged, it follows that the halo so produced is a limited circular arc whose centre is the zenith.

From the equation for minimum refraction,

$$\sin \frac{D_0 + A}{2} = \mu \sin \frac{A}{2},$$

it appears that in the present case, and for $\mu = 1.31$,

$$D_0 = 45° \, 44'.$$

This corresponds to $H = 22° \, 8'$, and to $H' = 67° \, 52'$. In this case

$$H' - H = 45° \, 44',$$

which is the radius of the 46° halo.

With increase or decrease of the altitude of the sun from 22° 8′, the solar distance of the circumzenithal arc increases, but so slowly at first that the gain amounts to only about 1° when the sun has sunk to 16°, or risen to 27°. Hence, this arc is also, though erroneously, called the upper tangent arc of the halo of 46°.

When the sun is on the horizon the solar distance of the circumzenithal arc is 57° 48′, and the interval between it and the 46° halo 12° 4′. On the other hand, the arc rapidly converges on the zenith as the altitude of the sun approaches 32°, and is theoretically impossible for solar altitudes greater than 32° 12′.

*Kern's Arc.*—Kern's arc, so designated from the name of the first observer to report [195] it, occurs exactly opposite the corre-

[195] *Koninklijk nederlandsch meteorologisch Instituut. Onweders, optische verschijn., enz., in Nederland,* 1895, O. 66.

sponding circumzenithal arc and on the same circle. It might, therefore, also be called the anticircumzenithal arc.

No explanation of this arc is at hand. Its theory, however, appears to be identical with that of the circumzenithal, with the single exception that while the latter is produced by light transmitted at $R$ (Fig. 166) the former, which is much the fainter of the two,[196] is due to that portion of the light which is there reflected, thus producing the image $S''$.

*Circumhorizontal Arc.*—A colored arc, red on the upper side, of perhaps 90° in extent, is occasionally seen parallel to the horizon and about 46°, or a little more, below the sun. This arc is produced by light entering snow crystals through vertical sides and passing out through horizontal bases, and, therefore, the theory of its formation is identical with that of the circumzenithal arc. On merely substituting "zenith distance" for "elevation" all the numerical values of the one become those of the other. Hence, the circumzenithal arc cannot appear when the zenith distance of the sun is greater than 32° 12′. Similarly, when this distance is 22° 8′, corresponding to minimum refraction, the solar distance of the circumhorizontal arc is 45° 44′, the radius of the halo of 46°. Further, for all values of the zenith distance of the sun from 16° to 27° the circumhorizontal arc is within 1° of tangency to the halo of 46°. Hence, it is also, though incorrectly, called the lower tangent arc of the halo of 46°.

*Lateral Tangent Arcs of the Halo of 46°.*—Just as flat-topped crystals with vertical sides produce a circumzenithal arc when the altitude of the sun is between 0° and 32° 12′, so, too, similar crystals whose axes are horizontal and directed towards any point whose solar distance is between 90° and 57° 48′, or between 0° and 32° 12′, produce a colored arc—red next the sun—about this directive point as a centre. And as there are two such points corresponding to each solar distance, one to the right, the other to the left, of the solar vertical, it follows that arcs formed in the above manner are symmetrically situated with respect to this vertical. Further, when the solar distance of the directive point is 67° 52′ or 22° 8′, the resulting arc is tangent to the halo of 46°, and as always some, at least, of the innumerable crystals are turned towards this point, except when the altitude of the sun is greater than these values, respectively, it follows, with the

[196] *Monthly Weather Review*, 34, p. 124, 1906.

same exceptions, that the blend of the numerous arcs produced by the various directed crystals is always tangent to the halo of 46°, and also that except near the point of tangency only the red of these blends is reasonably pure.

Obviously, there are two classes of lateral tangent arcs, namely, lower, as seen at $S_1$ by an observer at $O_1$ (Fig. 164), and upper, as seen at $S_2$ by an observer at $O_2$. These will next be considered separately as infralateral and supralateral arcs.

*Infralateral Tangent Arcs of the Halo of 46°.*—Let the circle about $S$ (Fig. 167) be the halo of 46°; let the altitude, $H$, of the sun be less than 67° 52′, and let the principal axes of the columnar crystals be horizontal and directed towards the point, $P$, on the horizon distant 67° 52′ from $S$. As previously explained, the infralateral tangent arcs will be tangent to this halo at the point $T$, where it is intersected by the arc $SP$. The position of $T$ may easily be determined from the value of the angle $A$, between the vertical $SB$ and the arc $SP$.

Obviously, from the right spherical triangle, $SBP$,

$$\cos A = \tan H \cot 67° \ 52'.$$

Since refraction by the crystal is limited to solar distances of $P$ between 57° 48′ and 90°, it follows that $A_1$ and $A_2$, corresponding to the lower and upper ends of the tangent arc, are given by the equations,

$$\cos A_1 = \tan H \cot 57_\circ \ 48'$$

and

$$A_2 = 90°,$$

respectively.

When the altitude of the sun is 57° 48′, or a little greater, the two tangent arcs, springing from a common point on the solar vertical, form a wide V.

When the solar altitude equals 67° 52′, the two arcs, now merged into a smooth continuous curve, are tangent to the halo at its lowest point.

Finally, for altitudes of the sun greater than 67° 52′, the arcs, still appearing as a single curve, are slightly separated from the circular halo even at its lowest and closest point.

*Supralateral Tangent Arcs.*—When the altitude of the sun is less than 22° 8′ supralateral tangent arcs similar to the infralateral are produced.

The point of tangency of the supralateral tangent arc with the halo of 46° is given in terms of the arc, $A$, on this halo from its upper point.

When the solar altitude, $H$, is less than 22° 8′,

$$\cos A = \tan H \cot 22^\circ\ 8'.$$

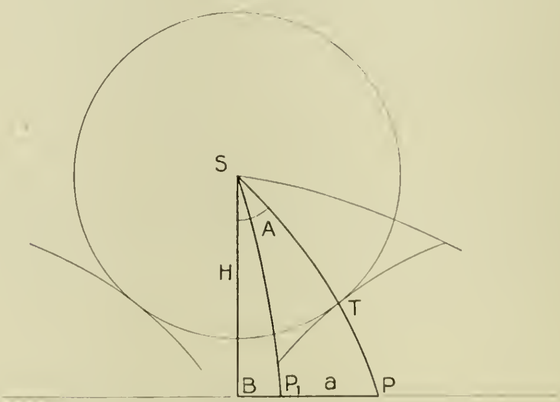
Similarly, the possible end of the arc is given by the equation,

$$\cos A' = \tan H \cot 32^\circ\ 12'.$$

When the altitude of the sun is 22° 8′, both arcs, forming a continuous curve, are tangent to the halo at its highest point.

Finally, for altitudes between 22° 8′ and the extreme limit,

FIG. 167.




Formation of the lateral tangent arcs of the halo of 46°.

32° 12′, these arcs are more or less above the halo of 46°.

The following table gives the value of $A$ for different altitudes of the sun.

Infralateral arcs.

| $H$ | $A$ |
|---|---|
| 0° | 90° 0′ |
| 10° | 85° 54′ |
| 20° | 81° 35′ |
| 30° | 76° 25′ |
| 40° | 70° 03′ |
| 50° | 61° 00′ |
| 60° | 45° 13′ |
| 67° 52′ | 0° 0′ |

Supralateral arcs.

| $H$ | $A$ |
|---|---|
| 0° | 90° 0′ |
| 5° | 77° 35′ |
| 10° | 64° 18′ |
| 15° | 48° 47′ |
| 20° | 26° 30′ |
| 22° 8′ | 0° 0′ |
| 25° | 0° 0′ |
| 30° | 0° 0′ |
| 32° 12′ | 0° 0′ |

*Halos of Unusual Radii.*—Halos of various radii other than those already given have occasionally been reported. They can readily be accounted for on the assumption that the columnar ice crystals have certain pyramidal bases that afford the appropriate refraction angles.

*Secondary Halos.*—Obviously, each bright spot of the primary halo phenomena, especially the upper and lower points of the 22° circle and its parhelia, must in turn be the source of secondary halos. Doubtless, the 22° halos of the lateral parhelia contribute much to the flaring vertical column through the sun that occasionally has been seen; and, perhaps, the brilliant upper and lower points of the halo of 22° may produce faint secondary parhelic circles. In general, however, very few of the secondary halos are ever bright enough to be seen even when carefully looked for.

*Singular Halos.*—A few halos not included in any of the above classes have been *once* reported. No satisfactory explanations of them have been offered. Clearly, though, since the ice crystal appears in many modified forms—with flat tubular, and pyramidal ends, for instance—and even in orderly clusters, it is obvious that although only a few halos are well known, a great many are possible.

## CHAPTER V.

### REFLECTION PHENOMENA.

A FEW optical phenomena of the atmosphere, usually classed as halos, are produced by simple reflection.

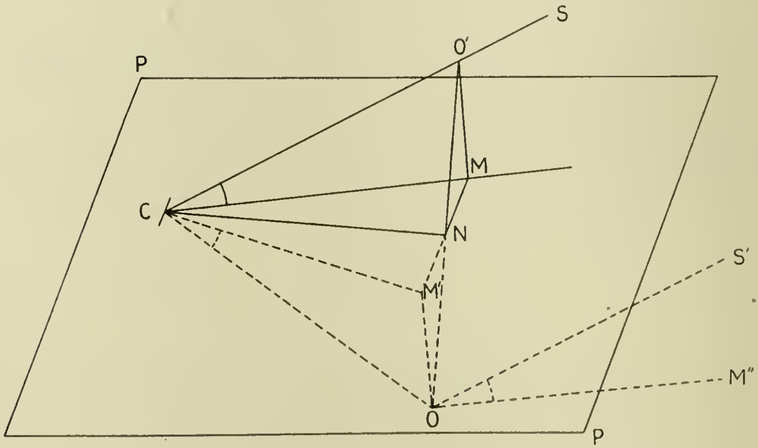
*Parhelic Circle.*—Very occasionally, a white circle, perhaps faint and tending to be diffuse, passes through the sun parallel to the horizon and, therefore, crosses the positions of the parhelia, anthelion, paranthelia, etc. This circle is produced by simple reflection (hence it is white) from vertical faces of ice crystals, as may easily be demonstrated.

To this end, let $PP$ (Fig. 168) be a plane parallel to the horizon and normal to a vertical face of an ice crystal at $C$. Let $SC$ be an incident ray reflected to the observer at $O$. Let $CN$ be normal to the reflecting face, and lie in the plane $PP$. By the laws of reflection, $CS$, $CN$, and $CO$ lie in a common plane, and the angle $SCN$ = the angle $OCN$. If, now, $CO' = CO$,

and $O'M$ and $OM'$ be drawn normal to the plane $PP$, it is obvious that the triangle $NMO'$ = the triangle $NM'O$, and that $MO' = M'O$. Hence, as the angles $CMO'$ and $CM'O$ are right angles, and $CO' = CO$, the angle $MCO'$, that is, the elevation of the sun above the plane $PP$, or above the plane of the horizon to which $PP$ is parallel = the angle $M'CO$, the angle of depression at $C$ of $O$ below the plane $PP$, or angle of elevation of the crystal, $C$, above the observer's horizon.

But $C$ is the position of any *vertical* face that reflects light to the observer at $O$. Hence, the parhelic circle passes through the sun and is parallel to the horizon. Hence, also, it is superimposed upon such parhelia and parhelic tails as may coexist. Occasionally, therefore, one may be unable to distinguish between a

FIG. 168.




Formation of the parhelic circle.

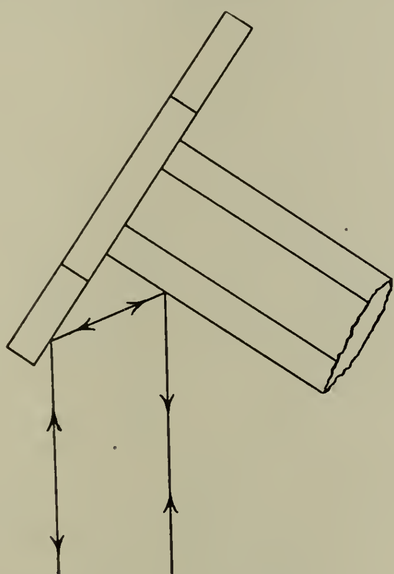
portion of a parhelic tail and a segment of the parhelic circle. There can be no doubt, however, in regard to any portion that occurs nearer the sun than the appropriate positions of the parhelia of 22°. Such portion cannot be produced by refraction, and, consequently, must belong to the parhelic circle.

Since the formation of this circle requires a predominance of vertical faces, and since a simple columnar hexagonal prism tends not only to keep its major axis horizontal but also one of its faces down, it follows that the required vertical surfaces must be either the flat ends of such crystals, or, most probably, the hex-

agonal faces of columnar crystals with tabular capped ends (Fig. 151). In the latter case, parhelia are also very likely to appear, while in the former they are apt to be entirely absent, and even the parhelic circle itself too faint to be clearly observed.

*Anthelion.*—On rare occasions a bright white spot, known as the anthelion, is seen on the parhelic circle opposite the sun. Of course, all crystals that contribute to the production of the parhelic circle also add to the brightness of the anthelion, but as the latter sometimes occurs when the circle is inconspicuous, or not even seen, it follows that the supplementary light must

FIG. 169.



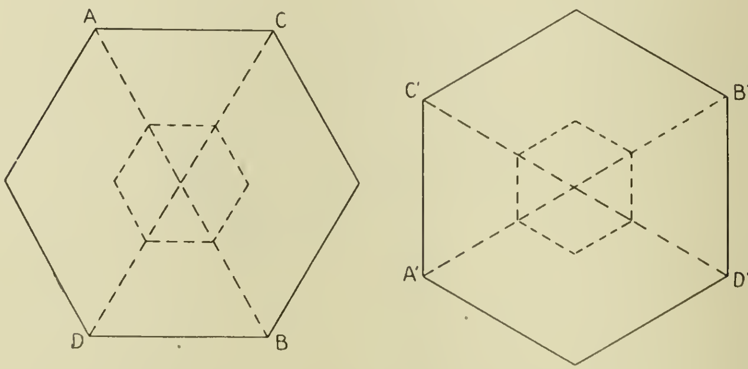
Formation of the anthelion.

be accounted for in some other way. A possible explanation is found in the action of columnar crystals with tabular caps at each end (Fig. 151). When both caps are the same size, or nearly so, and the columnar portion rather long the principal axes of such crystals must tend to remain horizontal, whatever the amplitudes of their oscillations. Now, whenever a crystal of this kind is horizontal, and one pair of its hexagonal faces vertical, light incident at whatever angle on either of these faces and finally reflected by the cap, or the reverse (see Fig. 169), will take such a course that the inclination of the reflected ray to

the plane of the horizon will be the same as that of the incident ray, and the projected directions on this plane exactly opposite to each other. Hence, this type of crystal will send much light to an observer from that point of the parhelic circle directly opposite the sun, enough, perhaps, when such crystals are particularly abundant, to produce a noticeably bright anthelion.

*Oblique Arcs of the Anthelion.*—On several occasions from one to four oblique white arcs have been seen to pass through the anthelion. Usually, when they occur, there are two such arcs symmetrically placed on either side of the vertical. The cause of these arcs is not definitely known, but as they are white (only once reported to show colors) it appears that presumably they are owing to reflection.

Fig. 170.




*A* *B*

End views of columnar crystals with tabular caps.

Possibly some, at least, of these arcs may be caused as follows:

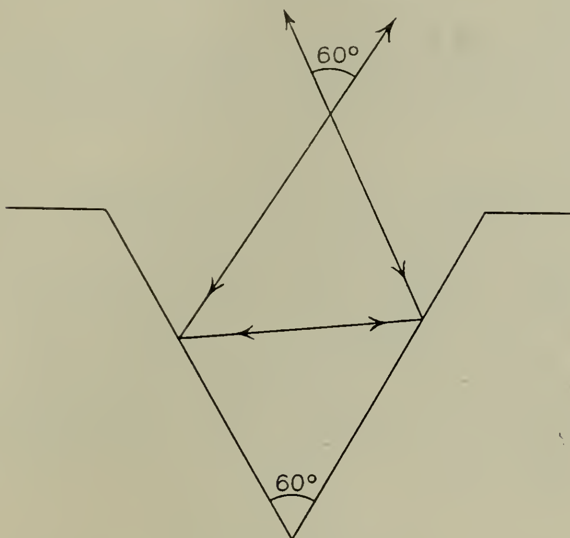
Let Fig. 170 A and B be end-on views of horizontal columnar crystals with tabular caps. A's position seems to be the stablest for crystals falling in still air, while B's position, perhaps, is one of secondary stability.

If, now, these crystals should oscillate about their diagonals, *AB*, *CD*, etc., as possibly they do, they clearly would produce white arcs through the anthelion, symmetrically arranged on either side of its vertical. Crystals in the *A* position would give arcs diverging 120° from each other, while the angle between

the arcs produced by crystals in the *B* position would be only half as great, or 60°.

*Parhelia of 120°.*—Bright spots that show no trace of color are occasionally seen on the parhelic circle 120° from the sun, in azimuth, or 60° from the anthelion. These are known as the parhelia of 120°, and while their origin is not certain, the fact that they are white is well nigh conclusive evidence that they are somehow produced by simple reflection, possibly from the faces of reëntrant angles.

FIG. 171.




Formation of parhelia of 60°.

These angles, which are of frequent occurrence in tabular crystals, are of two values, 60° and 120°, respectively, as shown in Figs. 171 and 172. And since such crystals fall more or less flatwise, the polygonal faces tend to remain vertical. Hence, when the crystals are rather thick and the faces of the reëntrant angles, therefore, sufficiently broad, light incident on one such face may be reflected to its companion and then from it in turn in such direction that the projections of the initial and final rays onto the plane of the horizon will differ in direction by 120°, as is obvious from Figs. 171 and 172. Both angles produce the

same effect, though, owing to the value of the angles of incidence involved, the 120° one presumably is the most effective.

*Parhelia of 90°*.—The brightest spots that on rare occasions are on the parhelic circle midway between the sun and the anthelion, that is, the parhelia of 90° probably are owing merely to the intersection of this circle with the halo of 90°. Both circles are white, and, therefore, the brighter spots produced by their intersection are also white.

*Pillars.*—During very cold weather vertical pillars of white light are often seen extending above and below the sun, when its elevation is small, or merely rising above it, when it is on the horizon.

The upper and lower portions of these pillars, counting from the sun, are owing, as has long been known, merely to reflection by the under and the upper surfaces, respectively, of tabular ice crystals.

*Crosses.*—On very rare occasions strips of white light have been seen to intersect over the sun at right angles. This rare phenomenon is owing, presumably, merely to the simultaneous occurrence of a parhelic circle, or segment of it next the sun, and a light pillar. Possibly it might also be produced by the intersection of the secondary halos of 22°, or even by some combination of "pillar," parhelic circle, and secondary halos. A competent observer, however, could easily distinguish between the several possible causes of a light "cross," and thus determine the actual origin of any particular instance of this phenomenon he might happen to see.

## Chapter VI.

### DIFFRACTION PHENOMENA.

*Coronas.*—Coronas consist of one or more sets of rainbow-colored rings, usually of only a few degrees radius, concentrically surrounding the sun, moon, or other bright object when covered by a thin cloud veil. They differ from halos in having smaller (except in rare cases) and variable radii, and in having the reverse order of colors; that is, blue nearest the sun, say, and red farthest away.

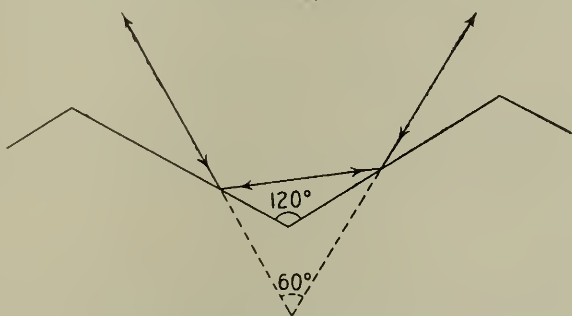
Clearly, then, coronas are caused by diffraction, or the distribution of effective (non-neutralizing) quantities of light off

the primary path, resulting from the action of cloud particles on radiation incident from a distant source.

Consider, then, the diffractive action of a layer of innumerable water droplets on a parallel beam of monochromatic light.

In this case the wave front, or continuous locus of any given phase, is flat—pits and pimples on it would quickly be smoothed out by dispersion—and everywhere normal to the line of travel. Also the droplets, because of their very short focal lengths and consequent great dispersive power, affect the parallel beam substantially as would so many opaque disks each of the size of a great circle of the corresponding droplet and normal to the line of travel. Furthermore, as the incident light is parallel the centres of the droplets may be regarded as lying in a common plane, each being located where the line of sight to its actual position intersects the plane in question.

FIG. 172.




Formation of parhelia of 120°.

The problem, then, reduces to that of finding the diffraction pattern produced in an isotropic transparent medium by a great many irregularly distributed opaque disks on a plane wave front of monochromatic light.

For the solution of this problem, it is convenient to make use of the fact, first explained by Huygens, and later developed by Fresnel, Stokes, Rayleigh and others (see any good work on optics), that each point in a wave front may itself be regarded as a secondary source of light of the same color.

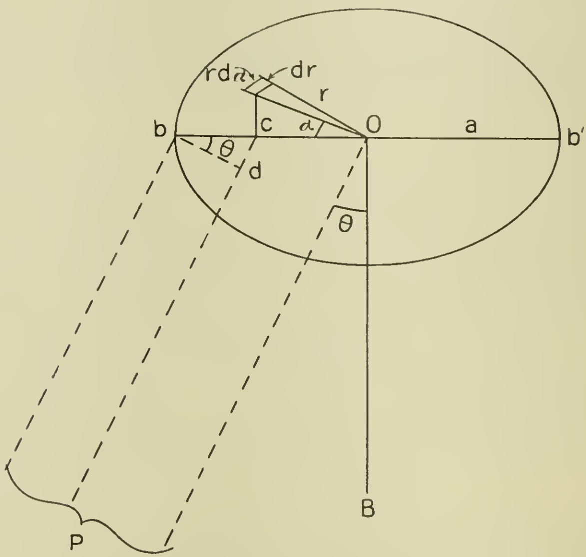
According to Stokes,[197] the intensity in different directions of the secondary radiation is proportional to $1 + \cos\theta$, in which

[197] *Math. and Phys. Papers*, vol. ii, p. 243; *Camb. Phil. Trans.*, 9, 1, 1849.

$\theta$ is the angle of deviation from the course of the parent light. That is, it is symmetrically distributed about the normal to the wave front at the secondary source, with its maximum value straight forward and minimum (zero) directly back.

A further aid to the solution of this problem is furnished by Babinet's principle, which may be explained as follows: When parallel light passes through a large opening in an opaque screen, but little illumination occurs outside the primary beam, and that little owing to rays from the edge of the opening whose angle of deviation from the original direction is very small. If,

FIG. 173.




Diffraction by a circular opening.

now, this large opening should be partially covered by a great many opaque disks, as assumed in the problem under consideration, and if illumination should result, as it does, at places where formerly there was complete shadow, then, if the opaque disks should become transparent and the transparent interspaces opaque, precisely the same illumination in the "shadow region" would obtain as before, but in exactly the opposite phase, as is obvious from the fact that the two illuminations acting together produce darkness.

Babinet's principle, therefore, enables one to use circular

openings and opaque disks interchangeably in the solution of diffraction problems. And as it is easier to discuss the circle mathematically than an irregular area the above problem will be substituted by its physical equivalent. That is, circular openings in an opaque screen will be substituted for opaque disks on a wave front.

Let $O$ (Fig. 173) be the centre of a small circular opening of radius $a$ in an opaque screen, and let parallel light pass through this opening, normal to its plane, in the direction $OB$. Let the plane fixed by $P$, the point whose illumination is to be determined, and the line $OB$ intersect the circle in the diameter $bb'$, and let the angle $BOP = \theta$. Finally, let $r$ be the distance of any element of the circle from the centre, $O$, $c$, the foot of the perpendicular from this element onto the diameter $bb'$, and $\alpha$ the angle between $r$ and the radius $Ob$.

Clearly, then, the difference of phase at $P$ between light from an element of the wave front at $b$ and from any other element is given by the expression

$$2\pi \frac{cd}{\lambda}, \text{ or } \frac{2\pi}{\lambda} (a - r \cos\ ) \alpha \sin \theta,$$

in which $\lambda$ is the wave-length. Also, since the displacement at $P$ owing to the element at $b$ is given by the expression

$$\sin 2\pi \frac{t}{T}\, r\, d\alpha\, dr.$$

in which $t$ is the time of travel from $b$ to $P$ and $T$ the period, the total displacement, $X$, at $P$ is given by the equation,

$$X = \int_0^{2\pi} \int_0^a \sin 2\pi \left[ \left( \frac{t}{T} - \frac{a \sin \theta}{\lambda} \right) + \frac{r \sin \theta}{\lambda} \cos \alpha \right] r\, d\alpha\, dr.$$

Hence, developing, and putting

$$\int_0^{2\pi} \int_0^a \cos 2\pi \left( \frac{r}{\lambda} \sin \theta \cos \alpha \right) r\, d\alpha\, dr = A$$

and

$$\int_0^{2\pi} \int_0^a \sin 2\pi \left( \frac{r}{\lambda} \sin \theta \cos \alpha \right) r\, d\alpha\, dr = B$$

$$X = A \sin 2\pi \left( \frac{T}{t} - \frac{a \sin \theta}{\lambda} \right) + B \cos 2\pi \left( \frac{t}{T} - \frac{a \sin \theta}{\lambda} \right).$$

Therefore, $A$ and $B$ are components at right angles to each other of the resultant amplitude. Hence, the intensity, $I$, is given by the equation,

$$I = A^2 + B^2.$$

Putting

$$\frac{\pi r \sin \theta}{\lambda} = \beta r$$

$$A = \int_0^{2\pi} \int_0^a \cos (2\beta\, r \cos \alpha)\, d\alpha\, r\, dr$$

$$= \int_0^{2\pi} \int_0^a \left[ 1 - \frac{(2\beta\, r \cos \alpha)^2}{1.2} + \frac{(2\beta\, r \cos \alpha)^4}{1 \cdot 2 \cdot 3 \cdot 4} - - - - \cdot \right] d\alpha\, r\, dr$$

But

$$\int_0^{2\pi} \cos^2 n\alpha d\alpha = \frac{1 \cdot 3 \cdot 5 \cdot \ldots\ldots 2n - 1}{2 \cdot 4 \cdot 6 \cdot \ldots\ldots 2n} 2\pi$$

Hence,

$$A = \pi \int_0^a \left[ 2r\, dr - \frac{2\beta^2 r^3\, dr}{1} + \frac{2\beta^4\, r^5\, dr}{(1 \cdot 2)^2} - \frac{2\beta^6\, r^7\, dr}{(1 \cdot 2 \cdot 3)^2} + - - - - \right]$$

$$= \pi \left[ a^2 - \tfrac{1}{2} \frac{\beta^2\, a^4}{1} + \frac{1}{3} \frac{\beta^4\, a^6}{(1 \cdot 2)^2} - \frac{1}{4} \frac{\beta^6\, a^8}{(1 \cdot 2 \cdot 3)^2} + - - - - - - \right]$$

and, putting

$$\beta\, a = \frac{\pi a \sin \theta}{\lambda} = m.$$

$$A^2 = \pi^2 a^4 \left[ 1 - \tfrac{1}{2} \frac{m^2}{1} + \frac{1}{3} \frac{m^4}{(1 \cdot 2)^2} - \frac{1}{4} \frac{m^6}{(1 \cdot 2 \cdot 3)^2} + - - - - \right]^2$$

A similar development gives the other component in terms of a series of odd valued sines of $\alpha$. Hence, as the elements are symmetrically distributed on either side of the diagonal $bb'$, $B = O$, and

$$I = A^2.$$

On giving $m$ various values, tables and curves of intensity may be constructed. The following table by Airy, copied from Mascart's "Traité d'optique," v. I, p. 310, is restricted to that portion of the expression within the brackets.

The following table of diffraction maxima and minima is also copied from Mascart, *l.c.*, p. 312.

| $m$ | $A$ | $I$ | $m$ | $A$ | $I$ |
|---|---|---|---|---|---|
| 0.0 | 1.0000 | 1.0000 | 3.0 | −0.0922 | 0.0085 |
| 0.1 | 0.9950 | 0.9900 | 3.1 | −0.0751 | 0.0056 |
| 0.2 | 0.9801 | 0.9606 | 3.2 | −0.0568 | 0.0032 |
| 0.3 | 0.9557 | 0.9134 | 3.3 | −0.0379 | 0.0014 |
| 0.4 | 0.9221 | 0.8503 | 3.4 | −0.0192 | 0.0004 |
| 0.5 | 0.8801 | 0.7746 | 3.5 | −0.0013 | 0.0000 |
| 0.6 | 0.8305 | 0.6897 | 3.6 | 0.0151 | 0.0002 |
| 0.7 | 0.7742 | 0.5994 | 3.7 | 0.0296 | 0.0009 |
| 0.8 | 0.7124 | 0.5075 | 3.8 | 0.0419 | 0.0017 |
| 0.9 | 0.6461 | 0.4174 | 3.9 | 0.0516 | 0.0027 |
| 1.0 | 0.5767 | 0.3326 | 4.0 | 0.0587 | 0.0035 |
| 1.1 | 0.5054 | 0.2554 | 4.1 | 0.0629 | 0.0040 |
| 1.2 | 0.4335 | 0.1879 | 4.2 | 0.0645 | 0.0042 |
| 1.3 | 0.3622 | 0.1312 | 4.3 | 0.0634 | 0.0040 |
| 1.4 | 0.2927 | 0.0857 | 4.4 | 0.0600 | 0.0036 |
| 1.5 | 0.2261 | 0.0511 | 4.5 | 0.0545 | 0.0030 |
| 1.6 | 0.1633 | 0.0267 | 4.6 | 0.0473 | 0.0022 |
| 1.7 | 0.1054 | 0.0111 | 4.7 | 0.0387 | 0.0015 |
| 1.8 | 0.0530 | 0.0028 | 4.8 | 0.0291 | 0.0008 |
| 1.9 | 0.0067 | 0.0000 | 4.9 | 0.0190 | 0.0004 |
| 2.0 | −0.0330 | 0.0011 | 5.0 | 0.0087 | 0.0001 |
| 2.1 | −0.0660 | 0.0044 | 5.1 | −0.0013 | 0.0000 |
| 2.2 | −0.0922 | 0.0085 | 5.2 | −0.0107 | 0.0001 |
| 2.3 | −0.1116 | 0.0125 | 5.3 | −0.0191 | 0.0004 |
| 2.4 | −0.1244 | 0.0155 | 5.4 | −0.0263 | 0.0007 |
| 2.5 | −0.1310 | 0.0172 | 5.5 | −0.0321 | 0.0010 |
| 2.6 | −0.1320 | 0.0174 | 5.6 | −0.0364 | 0.0013 |
| 2.7 | −0.1279 | 0.0164 | 5.7 | −0.0390 | 0.0015 |
| 2.8 | −0.1194 | 0.0143 | 5.8 | −0.0400 | 0.0016 |
| 2.9 | −0.1073 | 0.0115 | 5.9 | −0.0394 | 0.0016 |
| 3.0 | −0.0922 | 0.0085 | 6.0 | −0.0372 | 0.0014 |

*Diffraction Maxima and Minima.*

| | Maxima $\frac{m}{\pi}$ | Maxima Diff. | Maxima $I$ | Minima $\frac{m}{\pi}$ | Minima Diff. | Minima $I$ |
|---|---|---|---|---|---|---|
| 1 | 0.000 | | 1.00000 | 0.610 | | 0 |
| | | 0.819 | | | 0.506 | |
| 2 | 0.819 | | 0.01745 | 1.116 | | 0 |
| | | 0.527 | | | 0.503 | |
| 3 | 1.346 | | 0.00415 | 1.619 | | 0 |
| | | 0.512 | | | 0.502 | |
| 4 | 1.858 | | 0.00165 | 2.121 | | 0 |
| | | 0.504 | | | 0.501 | |
| 5 | 2.362 | | 0.00078 | 2.622 | | 0 |
| | | 0.500 | | | 0.500 | |
| 6 | 2.862 | | 0.00043 | 2.122 | | 0 |
| | | 0.500 | | | 0.500 | |
| 7 | 3.362 | | 0.00027 | 3.622 | | 0 |
| | | 0.500 | | | 0.501 | |
| 8 | 3.862 | | 0.00018 | 4.123 | | 0 |
| | | 0.500 | | | 0.500 | |
| 9 | 4.362 | | 0.00012 | 5.623 | | 0 |

It will be noticed that the decrease of intensity from maximum to minimum, though large at first, quickly becomes very small.

From the values of $\frac{m}{\pi}$, corresponding to diffraction minima, it is evident that

$$\sin \theta = (n + 0.22)\,\frac{\lambda}{2a}, \text{ very nearly,}$$

in which $n$ is the order of the minimum, counting from the centre.

This important equation gives the angular distance from the light source at which the successive diffraction minima occur for any particular wave-length and size of drop or disk. It also gives the diameter of the drop when the wave-length, angular distance from the centre, and order of the minimum are known. Furthermore, it shows that the larger the wave-length and the smaller the droplet the larger the diffraction circle, or halo.

The above discussion applies to a single circular disk on the wave front. An exact duplicate disk obviously would produce an exact duplicate diffraction pattern. If, then, two such disks occur close together, and if the distance between their centres, or other homologous points is $b$, and $\phi$ the angle between the line connecting these points and the line connecting the farthest to the point of observation, then the difference in phase between the two lights at the latter place is $2\pi\,\frac{b \sin \phi}{\lambda}$, and a secondary diffraction pattern, in addition to the two primary circular ones, is produced, directed at right angles to the line connecting the centres of the disks. Similarly, conspicuous diffraction patterns are produced by any regular geometric distribution of many disks.

Let, however, the disks, or droplets, be numerous, irregularly distributed, and all of the same size (if of various sizes their effects cannot easily be summed up). Let each produce at a given point a disturbance whose amplitude is $A$, but let the phases be $\epsilon_1, \epsilon_2$ - - - - - $\epsilon_n$, and let $R$ be the resultant amplitude.

Then,

$$R^2 = \Sigma\,(A \cos\epsilon)^2 + \Sigma\,(A \sin \epsilon)^2,$$

$$= A^2 \left[(\cos \epsilon_1 + \cos \epsilon_2 + \cdots + \cos \epsilon_n)^2 + (\sin \epsilon_1 + \sin \epsilon_2 + \cdots + \sin \epsilon_n)^2\right],$$

$$R^2 = A^2\,(n \cos^2\epsilon + n \sin^2\epsilon + 2n \cos \epsilon \cos \epsilon' + 2n \sin \epsilon \sin \epsilon'),$$

$$= A^2 n + 2A^2\,n \cos\,(\epsilon - \epsilon').$$

But as $n$ is large and the disks irregularly scattered, it is clear that the phase difference, $\epsilon - \epsilon'$, between the innumerable pairs will have all manner of values with, on the whole, the positive and negative well balanced. Hence, as close as can be detected,

$$R^2 = nA^2.$$

That is, the diffraction rings, corona, for instance, produced by a large number, $n$, of irregularly distributed neighboring droplets are the same as those produced by any one of them, but $n$ times as bright.

When the incident light is complex, the diffraction pattern produced by the several wave-lengths necessarily overlap and produce correspondingly colored rings—red, if present, being the outermost, and blue the innermost.

*Size of Cloud Particles.*—Since the diffraction pattern produced by a great many irregularly distributed droplets of uniform size is the same as that due to a single one, it is clear that the size of the cloud particles producing coronas may be determined by the equation,

$$\sin \theta = (n + 0.22) \frac{\lambda}{2a},$$

in which, as already explained, $\theta$ is the angular distance from the centre of the corona to the $n$th minimum corresponding to light of the wave-length, $\lambda$, and $a$, the radius to be determined.

Measurements made in this manner have shown that the radii of corona-producing cloud droplets, though varying over a considerable range, commonly average about .007 mm. to .010 mm.

It may be interesting to note in this connection that a contracting or decreasing corona implies growing droplets and, perhaps, the approach of rain; and that an expanding corona implies, on the other hand, decreasing or evaporating droplets and, presumably, the approach of fair weather.

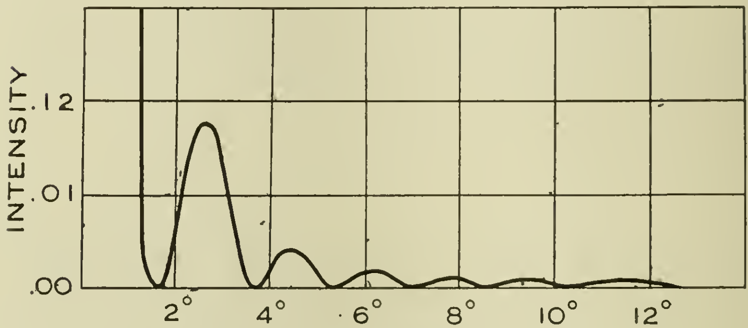
Fig. 174, copied from an instructive article by Simpson,[198] gives the angular and intensity distribution of the monochromatic light $\lambda = .000571$ mm. in a corona produced by droplets of .01 mm. radius.

*Droplets versus Ice Needles as Producers of Coronas.*—When

[198] Q. *Jr. Roy. Met. Soc.*, 38, p. 291, 1912.

coronas are seen in clouds whose temperature is above 0° C., or in which halos do not form, it is certain that they are due to droplets. It is well known, however, that the most brilliant coronas—those of multiple rings and large diameter—usually are formed by very high clouds whose temperature often must be far below freezing. Naturally, then, it has been inferred that these coronas are produced by the diffractive action of ice needles. Simpson,[199] however, appears to have disproved the probability that they are formed in this manner. "On no occasion," he says, referring to his stay in the Antarctic, "were a corona and halo seen at the same time on the same cloud." Furthermore, he explains, as the axes of the needles are essentially horizontal, this being their stable position, only those

FIG. 174.




Distribution of intensity by droplets, radius = 0.01 mm., $\lambda$ = .571 $\mu$.

at right angles to radii from the sun, or other luminary, could produce coronas of the kind observed, while the equally numerous crystals of every other orientation would produce such different patterns that the total effect probably could be but little more than white light—certainly nothing approaching the pure brilliant colors often seen in these coronas.

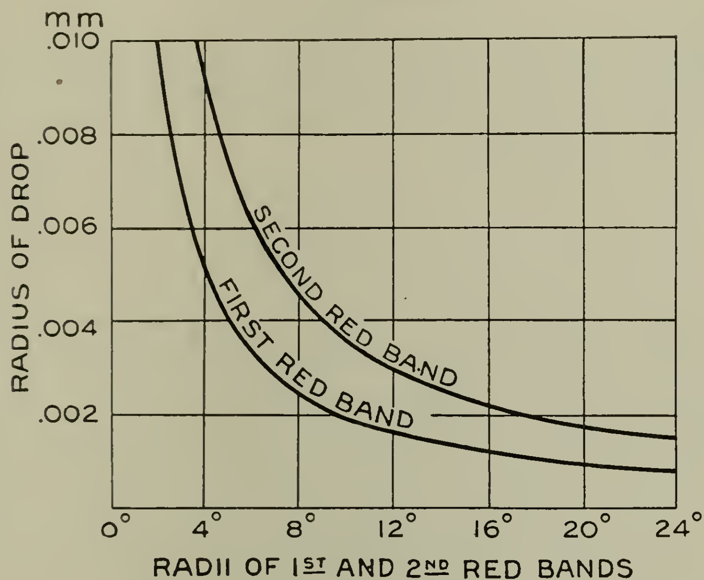
Presumably, therefore, the brilliant coronas of high clouds are due to very small undercooled water droplets of approximately uniform size, and not, as has generally been supposed, to ice needles.

*Iridescent Clouds.*—Thin and perhaps slowly evaporating

[199] *l. c.*

cirro-stratus and cirro-cumulus clouds occasionally develop numerous iridescent borders and patches of irregular shape, especially of red and green, at various distances from the sun up to 30° or more. A brilliantly colored iridescent cloud of considerable area is justly regarded as one of the most beautiful of sky phenomena, but one of which until recently there was no satisfactory explanation. Simpson,[200] however, has shown that the colored patches in question, presumably, are only fragments of coronas formed by exceedingly small droplets of very approximately

FIG. 175.




Relation between size of drop and size of corona.

uniform size. The relation between the radius of droplet and angular distances from the centre to the first and second red bands is shown in Fig. 175, also copied from the paper cited, from which it appears that coronas of the requisite size may occur, and, therefore, that the assumption that iridescent clouds are only fragments of unusually large and exceptionally brilliant coronas presumably is correct.

*Bishop's Ring.*—After the eruption of Krakatoa in 1883, of

[200] *l. c.*

Mont Pelé in 1902, and of Katmai in 1912, a faint reddish-brown corona was often seen, under favorable circumstances, around the sun. This is known as Bishop's ring, after Mr. Bishop of Honolulu, who first described it.

The width of this ring, as seen after the eruption of Krakatoa, was about 10°, and the distance from the sun to its outer edge, that is, to the first minimum, 22° to 23°. Substituting this value of the angular radius of the first minimum in the equation, explained above,

$$\sin \theta = (n + 0.22) \frac{\lambda}{2a}$$

and letting $\lambda = .000571$ mm., it appears that the diameter of the dust particles assumed either spheres or circular disks of approximately uniform size, that produced this peculiar corona as given by the equation,

$$2a = 1.22 \frac{.000571 \text{mm.}}{\sin 22° 30'}$$
$$= .00182 \text{ mm. about.}$$

*Glory or Brocken-Bow.*—When favorably situated, one occasionally may see rings of colored light around the shadow of his own head as cast upon a neighboring fog bank or cloud. This phenomenon, to which several names have been given—glory, Brocken-bow, Brocken-spectre, mountain-spectre—is produced by the diffraction by particles comparatively near the surface of light reflected from deeper portions of the fog or cloud.

The reflected light obviously emerges in every direction, but the nearer one looks along the path of incidence the larger the ratio of illuminated to non-illuminated particles in his line of sight. Indeed, at any appreciable angle from this special direction a considerable proportion of the droplets in one's vision evidently must lie in the shadows of others nearer the surface. Hence, not only will the shadow of one's head be surrounded by the brightest reflected light, like the "heiligenschein" one may see around the shadow of his head on a bedewed lawn, but it will also be the centre of the brightest and only perceptible glory or reflection halo, and that for the simple reason that the more intense the initial light the more brilliant its diffraction effects.

## CHAPTER VII.

### PHENOMENA DUE TO SCATTERING: COLOR OF THE SKY.

THE color of the cloudless sky, though generally blue, may, according to circumstances, be anything within the range of the entire spectrum. At great altitudes the zenithal portions are distinctly violet, but at moderate elevations often a clear blue. With increase of the angular distance from the vertical, however, an admixture of white light soon becomes perceptible that often merges into a grayish horizon. Just after sunset and also before sunrise portions of the sky often are distinctly green, yellow, orange, or even dark red, according especially to location and to the humidity and dust content of the atmosphere. Hence, these colors and the general appearance of the sky have rightly been used immemorially as more or less trustworthy signs of the coming weather.

Many attempts have been made to account for the blue of the sky [201]—the other colors being comparatively ignored. Some have held that it is just the nature of the atmosphere, or of particles in it, to reflect the blue of sunlight and to transmit the other colors. But as they did not explain how the atmosphere, or these particles, happened to have such nature the mystery actually remained as profound as ever. Another interesting hypothesis, suggested by Leonardo da Vinci, was to the effect that the blue is the resultant of a mixture of more or less white light, reflected by the atmosphere, with the black of space. But the futility of this idea is immediately obvious from the fact that gray alone could be produced by any such mixture.

The first logical attempt to explain (as that term is now understood) why the sky is blue was made by Newton,[202] who supposed it to be due to the same sort of interference between the rays reflected from the front and rear surfaces of transparent objects (in this case minute water drops) that produce the colors of soap bubbles. In fact, he thought that the "blue of the first order," the blue nearest the black central spot of the "Newton's rings," is of the same color as the blue of the sky, and that they were produced in the same way. This explanation, though erroneous, and based only on analogy, was accepted without modi-

[201] See summary and bibliography by Dorsey, *Monthly Weather Review* 28, p. 382, 1900.

[202] *Optics*, book ii.

fication for nearly 175 years. At about the end of this period, however, Clausius [203] demonstrated analytically that a cloud of droplets of the small size assumed by Newton would cause the stars and other celestial objects to appear enormously magnified. He, therefore, modified Newton's theory by assuming that the droplets are larger but vesicular with very thin walls. In this way the magnification trouble is avoided, but the theory is not improved. First, because water droplets are not hollow; and, second, because, as shown by Brücke,[204] the color of the sky differs radically from the blue of the "first order."

Although the above appears to have been the first serious criticism of the Newtonian theory of sky colors, observational and experimental data sufficient to render it untenable had long been known. This consisted of (*a*) Arago's [205] discovery in 1811 that sky light is partially polarized and that this polarization is a maximum along a circle about 90° from the sun; and (*b*) Brewster's [206] discovery, shortly thereafter, that polarization by reflection is a maximum when the tangent of the angle of incidence is equal to the refractive index of the reflector divided by that of the adjacent medium.

If, then, sky light is the result of simple reflection, the angle of polarization (angle of incidence corresponding to maximum polarization) of the reflecting medium must be 45°—since the arc of maximum polarization is 90° from the sun. But the angle of polarization of water in air is about 74°. Hence, the color of the sky cannot be due to reflection from water droplets, as Newton and many others assumed.

The real origin of the blue of the sky, scattering of light by particles far too small to reflect specularly, appears to have been first indicated by Brücke's [207] experiments, which showed (*a*) that a transparent medium, rendered turbulent by sufficiently small particles, appears blue when illuminated with white light; and (*b*) that objects may be seen through such medium clearly and distinctly. A few years later, Tyndall [208] made a large number of experiments on the action of chemically formed "clouds"

[203] *Crell's Jr.*, **34**, p. 122, 1847; p. 185, 1848; *Pogg. Ann.*, **72**, p. 294, 1847.

[204] *Pogg. Ann.*, **88**, p. 363, 1853.

[205] *Oeuvres*, **7**, p. 394, and p. 430.

[206] *Phil. Trans.*, **33**, p. 125, 1815.

[207] *l. c.*

[208] *Phil. Mag.*, **37**, p. 384, 1869; **38**, p. 156, 1869.

on incident white light, and found that not only did they scatter blue light when their particles were very small, but also that this light was completely polarized at right angles to the incident beam. Here, then, was the experimental solution of the problem of the blue of the sky and its polarization. About two years later, Lord Rayleigh [209] supplied the necessary theory, and thus, at last, one of the oldest and most difficult of the many problems of meteorological optics became completely solved. In a later paper Lord Rayleigh [210] showed that in the absence of dust of all kinds "the light scattered from the molecules [of air] would suffice to give us a blue sky, not so very greatly darker than that actually enjoyed." And still later, King [211] concluded that "The analysis of the present paper seems to support the view that at levels about Mount Wilson [1730 metres] molecular scattering is sufficient to account completely both for attenuation of solar radiation and for the intensity and quality of sky radiation." However, whether the scattering be by fine dust or by individual molecules the theory is the same, and, as developed in Rayleigh's first paper, substantially as follows:

Let a beam of light of wave-length $\lambda$ be incident, say, to be definite, from the zenith. There will be little or no scattering from that portion of the beam in free ether, as is obvious from the facts ($a$) that extremely distant stars are still visible, and ($b$) that interstellar spaces are nearly black. From the portion in the atmosphere, however, there is abundant lateral scattering by the innumerable particles of dust and molecules of air, each of which is optically denser than the ether and so small in comparison to $\lambda^3$ that the applied force is practically constant throughout its volume. Each such particle merely increases local inertia of the ether, and, thereby, since the rigidity is not affected, correspondingly reduces the amplitude of a passing light wave. If, then, a force should be applied to each particle, such as to counterbalance the increasing inertia, the light would pass on exactly as in empty space and, therefore, without scattering. On the other hand, precisely the same force, but reversed in direction, if acting alone on free ether would produce the same effect that the disturbing particle produces. This force obvi-

[209] *Phil. Mag.*, **41**, pp. 107, 274, 447, 1871; **12**, p. 81, 1881.
[210] *Phil. Mag.*, **47**, p. 375, 1899.
[211] *Phil. Trans.*, *A.*, **212**, 375, 1913.

ously must have the same period and direction as the undisturbed luminous vibrations and be proportional to the difference in optical density between the particle and the ether.

The only factors that conceivably can affect the ratio of the amplitude of scattered to incident light are: direction, or, rather, angle between directions of force and point of observation; ratio between the optical densities of the disturbing particle and the ether; volume of particle; distance from particle; wave-length; and velocity of light. Hence, in comparing the extents to which lights of different colors are scattered, the first two factors may be neglected, since they apply in equal measure to all. Furthermore, as the ratio in question, like all ratios, is a mere number and, therefore, dimensionless, the last factor must be omitted, since it and it alone involves time. There remain, then, only the volume of the particle, distance from it, and the wave-length to consider. But from the dynamics of the problem it appears that the ratio of the two amplitudes must vary directly as the volume of the particle and inversely as the distance from it. That is,

$$N = \frac{L^3}{L} f(\lambda),$$

in which $N$ is some number, $L$ a unit of length, and $f(\lambda)$ that function of $\lambda$ that renders the equation dimensionless. Hence,

$$f(\lambda) = \lambda^{-2},$$

and, therefore, the ratio of the two intensities is proportional to $\lambda^{-4}$. Obviously, then, light from a serene sky should belong essentially to the blue or short wave-length end of the spectrum.

If, as commonly expressed, the displacement in the incident wave is $A \cos\left(\frac{2\pi\, v\, t}{\lambda}\right)$, in which $A$ is the amplitude; $v$ the velocity of light, $\lambda$ the wave-length; and $t$ the time since any convenient interval when the displacement was $A$, then the corresponding acceleration is

$$\frac{d^2}{dt^2} A \cos \frac{2\pi\, v\, t}{\lambda} = -A \left(\frac{2\pi}{\lambda} v\right)^2 \cos \frac{2\pi}{\lambda} vt.$$

Hence, the force that would have to be applied to a sufficiently minute particle in order that the wave might pass over it undisturbed is

$$-(D' - D)\, T\, A \left(\frac{2\pi\, v}{\lambda}\right)^2 \cos \frac{2\pi}{\lambda} vt.$$

in which $D'$ and $D$ are the optical densities of the particle and ether, respectively; and $T$ the volume of the particle. And this, as explained, is also the expression for the force which, if operating alone on the ether, would produce the same light effects that actually are induced by the particle in question.

Now it has been shown by Stokes,[212] and also by Lord Rayleigh,[213] that the displacement $X$ produced by the force $F \cos \frac{2\pi\, vt}{\lambda}$ is given by the expression,

$$X = \frac{F \sin\alpha}{4\pi\, v^2 D\, r} \cos \frac{2\pi}{\lambda} (vt - r)$$

in which $\alpha$ is the angle between the direction of the force and the radius vector, $r$, that connects the centre of the force with the point at which the displacement is observed.

On substituting for the force $F \cos \frac{2\pi\, v\, t}{\lambda}$ its value, one finds that

$$X = A \frac{D' - D}{D} \frac{\pi\, T}{r\, \lambda^2} \sin\alpha \cos \frac{2\pi}{\lambda} (v\, t - r)$$

Hence, the intensity of the light scattered by a single particle is

$$A^2 \left(\frac{D' - D}{D}\right)^2 \frac{\pi^2 T^2}{r^2 \lambda^4} \sin^2\alpha.$$

and for a cloud

$$A^2 \left(\frac{D' - D}{D}\right) \frac{\pi^2 \sin^2\alpha}{\lambda^4} \Sigma \frac{T^2}{r^2},$$

in which $\Sigma \frac{T^2}{r^2}$ is the sum of the values of $\frac{T^2}{r^2}$ for all the particles in the line of sight, or

$$A^2 \left(\frac{D' - D}{D}\right)^2 \frac{\pi^2 \sin^2\alpha}{\lambda^4} N \left(\frac{T}{r}\right)^2_m$$

in which $N$ is the total number of particles in the line of sight, and $\left(\frac{T}{r}\right)^2_m$ the mean of the several values of $\left(\frac{T}{r}\right)^2$.

The above equations are based on the assumption that the displacements in the incident wave are all in the same plane—that the incident light is plane polarized. If, however, they lie in parallel planes, passing through the axis of propagation, that is, if the incident light is unpolarized, we may resolve each dis-

[212] *Camb. Phil. Trans.*, 9, p. 1, 1849; *Math. and Phys. Papers II*, pp. 243–328.

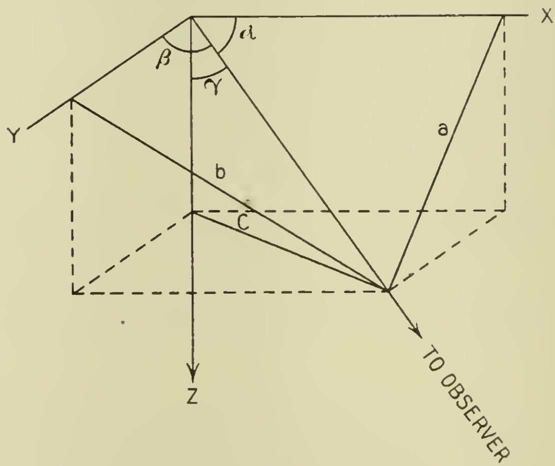
[213] *Phil. Mag.*, 41, p. 107, 1871.

placement, always normal to the line of travel, into two components at right angles to each other and obtain their joint effect in any given direction. Let the line from the centre of the force to the point of observation make the angles $\alpha$, $\beta$, and $\gamma$ with these components and the direction of travel, respectively. Then, since $\sin^2\alpha + \sin^2\beta = 1 + \cos^2$, (see Fig. 176), the intensity of the scattered light at the angle $\gamma$ from the direction of travel of a non-polarized beam is,

$$A^2 \left(\frac{D' - D}{D}\right)^2 \frac{\pi^2 (1 + \cos^2\gamma)}{\lambda^4} N \left(\frac{T}{r}\right)^2_m$$

According to this equation, the maximum amount of scattered

FIG. 176.




Intensity of scattered light in a given direction.

light is along the path—forward and back—of the incident beam, and least at right angles to it. Also, the intensity is directly proportional to the square of the volume of the disturbing particle, provided it is sufficiently small.

The effect of the size of particle on scattering as it approaches $\lambda^3$ is not well known. However, Lord Rayleigh[214] has shown that the intensity of the light scattered by relatively large spherical particles varies as the inverse 8th power of the wave-length.

*Extinction Coefficient.*—The intensity or brightness of solar or other radiation is decreased with increase of air path by (*a*)

[214] *Phil. Mag.*, 12, p. 81, 1881.

scattering, (*b*) selective absorption, (*c*) diffraction, (*d*) reflection, and (*e*) refraction. When the sky is clear, however, only (*a*) is particularly effective in the visual region, but here it is quite effective, since each disturbing particle evidently scatters energy from incident radiation in proportion to the expression,

$$\frac{\pi^2 T^2}{r^2 \lambda^4}\left(\frac{D' - D}{D}\right)^2 \int_0^\pi \sin^2 a 2\pi\ r^2 \sin a da = \frac{8\pi^3 T^2}{3 \lambda^4}\left(\frac{D' - D}{D}\right)^2.$$

Let $E$ be the energy delivered per unit cross-section of the incident beam in any interval of time, and let $n$ be the number of disturbing particles (all alike) per unit volume. Then the energy gain (negative) during the same time per unit cross-section, and penetration, $dx$, is given by the equation,

$$dE = -E\ n\ dx\ \frac{8\pi^3 T^2}{3\lambda^4}\left(\frac{D' - D}{D}\right)^2.$$

If, then, $E_0$ is the energy in the beam before any scattering took place, and $E$ the energy remaining after penetrating the distance $x$ into the turbulent medium in question,

$$E = E_0\ e^{-\epsilon x}$$

in which the extinction coefficient

$$\epsilon = \frac{8\pi n\ T^2}{3\ \lambda^4}\left(\frac{D' - D}{D}\right)^2.$$

But $D = \mu^2$ (from the equations, $v = \sqrt{\frac{\text{Elasticity}}{\text{Density}}} = \frac{1}{\mu}$, density of ether $= 1$, $\mu$ for either $= 1$), $\mu =$ refractive index. Also, in the case of scattering by air molecules, or by any small particles in a medium whose refractive idex is 1,

$$n\ T\left(\frac{D' - D}{D}\right) = D'' - 1$$

in which $D'' =$ average optical density of the turbulent space. If $\mu$ is the refractive index of the medium, air, say,

$$n\ T\left(\frac{D' - D}{D}\right) = \mu^2 - 1 = (\mu + 1)\ (\mu - 1) = 2\ (\mu - 1), \text{ nearly,}$$

since $\mu$ differs but little from unity.

Hence, substituting,

$$\epsilon = \frac{32\ \pi^3}{3\ n\lambda^4}\ (\mu - 1)^2, \text{ approximately.}$$

Clearly, then, the intensity of atmospheric and dust haze rapidly decreases with increase of wave-length, a fact that jus-

tifies the use, on aeroplanes, for instance, of "haze cutters" (filters that transmit only the longer waves) for both visual and photographic work. A fog haze, however, cannot be much cut. This is because the extinction it produces, being due, owing to the relatively large size of the fog droplets, chiefly to diffraction and reflection, is nearly equally effective for all colors.

The scattering of light by the molecules of the atmosphere and the suspended fine dust particles decrease the intensity of both the direct insolation and the scattered radiation, but at the same time gives to all portions of the sky, other than that occupied by the sun, a luminosity that otherwise would not exist—without scattering there would be no sky light at all. The residual sunlight and the total sky light vary greatly with time of day, latitude, altitude, season, weather, and dustiness of the atmosphere. Kimball,[215] for instance, finds "that photometric measurements made at Mount Weather, Va. [Lat. 39° 4′ N., Long. 77° 54′ W., altitude 526 m.], show that with a clear sky the total mid-day illumination on a horizontal surface varied from 10,000 foot-candles in June to 3600 foot-candles in January. It is less than the direct solar illumination on a normal surface from September to February, inclusive, but exceeds the latter from May to August, inclusive, for a period of from four to eight hours in the middle of the day.

"The illumination on a horizontal surface from a completely overcast sky may be half as great as the total illumination with a clear sky, and is frequently one-third as great. On the other hand, during severe thunderstorms at noon in midsummer, the illumination may be reduced to less than 1 per cent. of the illumination with a clear sky.

"The ratio of sky-light illumination to total illumination on a horizontal surface at noon in midsummer varies from one-third to one-tenth. In midwinter it varies from one-half to one-fifth.

"When the sky is clear, the twilight illumination on a horizontal surface falls to 1 foot-candle about half an hour after sunset, or when the sun is about 6° below the horizon."

*Prevailing Color.*—If $I_0$ is the initial intensity and $I_1$ the remaining intensity after penetrating the uniformly turbulent medium, the distance $x$, then,

$$I_1 = I_0 E^{-\frac{kx}{4}}$$

[215] *Monthly Weather Review*, 42, p. 650, 1914.

where

$$k = \frac{32\ \pi^3}{3\ n} (\mu - 1)^2.$$

This residual light, in turn, is scattered, and if $I_2$ is the intensity of the light scattered by a single particle at the angle $\alpha$ from the direction of displacement

$$I_2 = I_1 \frac{k'}{\lambda^4}$$

where

$$k' = \frac{\pi^2\ T^2}{r^2} \left(\frac{D' - D}{D}\right)^2 \sin^2\alpha,$$

and

$$I_2 = I_0 \frac{k'}{\lambda^4} e^{-\frac{kx}{\lambda^4}}.$$

Hence, the ratio of intensity received to initial intensity, or $I_2/I_0$, is small both for very long and very short wave-lengths. Its maximum value occurs at $\lambda^4{}_m = kx$, where

$$\left(\frac{I_2}{I_0}\right) = \left(\frac{I_2}{I_0}\right)_m \left(\frac{\lambda_m}{\lambda}\right)^4 e^{1 - \left(\frac{\lambda m}{\lambda}\right)^4},$$

or, if $I_0$ is uniform throughout the spectrum,

$$I_2 = I_m \left(\frac{\lambda_m}{\lambda}\right)^4 e^{1 - \left(\frac{\lambda m}{\lambda}\right)^4}.$$

According to Abbot, Fowle, and Aldrich,[216] the mean energy intensities of $I_0$, in arbitrary units, are:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\lambda$ = 0.39 | 0.42 | 0.43 | 0.45 | 0.47 | 0.50 | 0.55 | 0.60 | 0.70 |
| $I_0$ = 3614 | 5251 | 5321 | 6027 | 6240 | 6062 | 5623 | 5042 | 3644 |

The luminous intensities would show greater contrasts, since the eye is more sensitive to the mid-region of the visible spectrum than to either end.

From these values of $I_0$, and the equation for the intensity of $I_2$, it can be shown that the prevailing color of the clear sky, except when the sun is on or below the horizon, is neither violet nor red, but some intermediate color, generally blue, as we know by observation.

*Twilight Colors.*—As the sun sinks to and below the horizon during clear weather, a number of color changes occur over large portions of the sky, especially the eastern and western. The phenomena that actually occur vary greatly, but the following

[216] *Annals Astrophys. Obsy.*, Smithsonian Institution, 3, p. 197, 1913.

may be regarded as typical, especially for arid and semi-arid regions:

($a$) A whitish, yellowish, or even bronze glow of 5° or 6° radius that concentrically encircles the sun as it approaches the horizon, and whose upper segment remains visible for perhaps 20 minutes after sundown.

The chief contributing factors to this glow appear to be (1) scattering, which is a maximum in the direction, forward and back, of the initial radiation, and (2) diffraction by the dust particles of the lower atmosphere. In both cases blue and violet are practically excluded, owing to the very long air paths.

($b$) A grayish blue circle that rises above the eastern horizon as the sun sinks below the western. This is merely the shadow of the earth.

($c$) A purplish arch that rests on the earth shadow and gradually merges into the blue of the sky at a distance of perhaps 10°, and also fades away as the arch rises.

Obviously, any direct sunlight in the lower dusty atmosphere to the east must have penetrated long distances through the denser air, and thus have become prevailing red, while that reaching the higher atmosphere is still rich in blue and violet. Hence, the observer sees red light scattered from the first of these layers and blue to violet from the other, and thereby gets the effect of the superposition of the opposite ends of the visible spectrum, that is, purple. The effect is most pronounced when the luminous layers are seen more or less "end on." Hence, the light is brightest at the border of the earth shadow. The fact that the red component of the purple is from the lower atmosphere and the others from the higher is evident from the bluish crepuscular rays that often radiate, apparently, from the antisolar point—shadow streaks cast through the lower dust-laden air by western clouds or mountain peaks, often below the horizon.

($d$) A bright segment only a few degrees deep but many in extent that rests on the western horizon just after sundown. The lowest portion often is red and the upper yellowish. A product essentially of scattered light by the lower and dustier portions of the atmosphere, where the light before being scattered is already reduced essentially to the colors seen.

($e$) A purple glow covering much of the western sky, reaching its maximum intensity when the sun is about 4° below the

horizon and disappearing when it is about 6° below. The explanation of this purple glow in the western sky presumably is the same as that in the eastern sky as given above under (*c*). The crepuscular rays of this region, apparently radiating from the sun, often are greenish-blue.

(*f*) A faint purple glow covering the entire sky when the sun is 6° or more below the horizon, and gradually disappearing in the west when the sun is 16° to 18° below the horizon. This appears to be due to secondary scattering of light from the illuminated atmosphere far to the west.

*Duration of Astronomical Twilight. (Interval Between Times When the Upper Edge of the Sun is on and the True Position of Its Centre 18° Below the Horizon.)*

| Date | | North latitude | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0° | 10° | 20° | 25° | 30° | 32° | 34° | 36° | 38° | 40° | 42° | 44° | 46° | 48° | 50° |
| | | h.m. | h.m. | h.m. | h.m. | h.m. | h.m. | h.m. | h.m. | h.m. | h.m. | h.m. | h.m. | h.m. | h.m. | h.m. |
| January | 1 | 1 14 | 1 15 | 1 18 | 1 21 | 1 26 | 1 28 | 1 29 | 1 31 | 1 34 | 1 37 | 1 41 | 1 45 | 1 49 | 1 53 | 1 59 |
| | 11 | 1 14 | 1 14 | 1 18 | 1 21 | 1 25 | 1 27 | 1 29 | 1 31 | 1 33 | 1 36 | 1 39 | 1 43 | 1 37 | 1 52 | 1 57 |
| | 21 | 1 13 | 1 13 | 1 17 | 1 20 | 1 23 | 1 25 | 1 28 | 1 30 | 1 32 | 1 34 | 1 38 | 1 41 | 1 45 | 1 49 | 1 54 |
| February | 1 | 1 12 | 1 12 | 1 15 | 1 18 | 1 22 | 1 24 | 1 26 | 1 28 | 1 30 | 1 33 | 1 36 | 1 39 | 1 43 | 1 47 | 1 52 |
| | 11 | 1 11 | 1 12 | 1 14 | 1 17 | 1 21 | 1 23 | 1 25 | 1 27 | 1 29 | 1 32 | 1 34 | 1 37 | 1 41 | 1 45 | 1 49 |
| | 21 | 1 10 | 1 11 | 1 13 | 1 16 | 1 20 | 1 22 | 1 24 | 1 26 | 1 28 | 1 31 | 1 33 | 1 36 | 1 40 | 1 44 | 1 48 |
| March | 1 | 1 10 | 1 11 | 1 13 | 1 16 | 1 20 | 1 21 | 1 23 | 1 25 | 1 28 | 1 30 | 1 33 | 1 36 | 1 39 | 1 43 | 1 48 |
| | 11 | 1 09 | 1 10 | 1 13 | 1 16 | 1 19 | 1 21 | 1 23 | 1 25 | 1 28 | 1 30 | 1 33 | 1 36 | 1 39 | 1 43 | 1 48 |
| | 21 | 1 09 | 1 10 | 1 13 | 1 16 | 1 20 | 1 22 | 1 24 | 1 26 | 1 29 | 1 31 | 1 34 | 1 37 | 1 41 | 1 45 | 1 50 |
| April | 1 | 1 09 | 1 11 | 1 14 | 1 17 | 1 21 | 1 23 | 1 25 | 1 27 | 1 30 | 1 33 | 1 36 | 1 40 | 1 44 | 1 49 | 1 54 |
| | 11 | 1 10 | 1 11 | 1 15 | 1 18 | 1 22 | 1 24 | 1 27 | 1 30 | 1 33 | 1 36 | 1 39 | 1 43 | 1 48 | 1 54 | 2 00 |
| | 21 | 1 11 | 1 12 | 1 16 | 1 20 | 1 24 | 1 27 | 1 29 | 1 32 | 1· 36 | 1 39 | 1 43 | 1 48 | 1 54 | 2 01 | 2 08 |
| May | 1 | 1 12 | 1 13 | 1 18 | 1 22 | 1 27 | 1 30 | 1 33 | 1 36 | 1 39 | 1 43 | 1 48 | 1 54 | 2 01 | 2 10 | 2 20 |
| | 11 | 1 13 | 1·14 | 1 19 | 1 24 | 1 30 | 1 33 | 1 36 | 1 40 | 1 43 | 1 48 | 1 54 | 2 01 | 2 10 | 2 20 | 2 35 |
| | 21 | 1 13 | 1 15 | 1 21 | 1 26 | 1 32 | 1 36 | 1 39 | 1 43 | 1 48 | 1 54 | 2 01 | 2 10 | 2 20 | 2 35 | 2 58 |
| June | 1 | 1 14 | 1 16 | 1 23 | 1 28 | 1 35 | 1 38 | 1 41 | 1 46 | 1 52 | 1 59 | 2 07 | 2 18 | 2 31 | 2 54 | .... |
| | 11 | 1 15 | 1 17 | 1 24 | 1 29 | 1 36 | 1 40 | 1 44 | 1 49 | 1 55 | 2 02 | 2 12 | 2 23 | 2 40 | 3 11 | ... |
| | 21 | 1 15 | 1 18 | 1 24 | 1 29 | 1 37 | 1 41 | 1 45 | 1 50 | 1 56 | 2 03 | 2 13 | 2 25 | 2 44 | 3 19 | ... |
| July | 1 | 1 15 | 1 17 | 1 24 | 1 29 | 1 36 | 1 40 | 1 44 | 1 49 | 1 55 | 2 02 | 2 12 | 2 23 | 2 40 | 3 10 | ... |
| | 11 | 1 14 | 1 16 | 1 23 | 1 28 | 1 35 | 1 38 | 1 41 | 1 46 | 1 52 | 1 59 | 2 07 | 2 18 | 2 31 | 2 54 | ... |
| | 21 | 1 13 | 1 15 | 1 21 | 1 26 | 1 32 | 1 36 | 1 39 | 1 43 | 1 48 | 1 54 | 2 01 | 2 10 | 2 21 | 2 36 | 3 00 |
| August | 1 | 1 13 | 1 14 | 1 19 | 1 24 | 1 30 | 1 33 | 1 36 | 1 40 | 1 44 | 1 48 | 1 54 | 2 02 | 2 10 | 2 20 | 2 35 |
| | 11 | 1 12 | 1 13 | 1 18 | 1 22 | 1 27 | 1 30 | 1 33 | 1 36 | 1 39 | 1 43 | 1 48 | 1 54 | 2 01 | 2 10 | 2 20 |
| | 21 | 1 11 | 1 12 | 1 16 | 1 20 | 1 24 | 1 27 | 1 30 | 1 33 | 1 36 | 1 39 | 1 43 | 1 48 | 1 54 | 2 01 | 2 09 |
| September | 1 | 1 10 | 1 11 | 1 14 | 1 18 | 1 22 | 1 24 | 1 27 | 1 30 | 1 33 | 1 36 | 1 39 | 1 43 | 1 48 | 1 53 | 2 00 |
| | 11 | 1 09 | 1 11 | 1 13 | 1 17 | 1 21 | 1 23 | 1 25 | 1 27 | 1 30 | 1 33 | 1 36 | 1 39 | 1 44 | 1 49 | 1 54 |
| | 21 | 1 09 | 1 10 | 1 13 | 1 16 | 1 20 | 1 22 | 1 24 | 1 26 | 1 29 | 1 31 | 1 34 | 1 37 | 1 41 | 1 45 | 1 50 |
| October | 1 | 1 09 | 1 10 | 1 13 | 1 16 | 1 19 | 1 21 | 1 23 | 1 25 | 1 28 | 1 30 | 1 33 | 1 36 | 1 39 | 1 43 | 1 48 |
| | 11 | 1 10 | 1 11 | 1 13 | 1 16 | 1 19 | 1 21 | 1 23 | 1 25 | 1 28 | 1 30 | 1 33 | 1 36 | 1 39 | 1 43 | 1 48 |
| | 21 | 1 10 | 1 11 | 1 13 | 1 16 | 1 20 | 1 22 | 1 24 | 1 26 | 1 28 | 1 31 | 1 33 | 1 36 | 1 40 | 1 44 | 1 48 |
| November | 1 | 1 11 | 1 12 | 1 14 | 1 17 | 1 21 | 1 23 | 1 25 | 1 27 | 1 29 | 1 32 | 1 34 | 1 38 | 1 41 | 1 46 | 1 49 |
| | 11 | 1 12 | 1 12 | 1 16 | 1 18 | 1 22 | 1 24 | 1 26 | 1 28 | 1 30 | 1 33 | 1 36 | 1 40 | 1 43 | 1 47 | 1 52 |
| | 21 | 1 13 | 1 13 | 1 17 | 1 20 | 1 24 | 1 26 | 1 28 | 1 30 | 1 32 | 1 35 | 1 38 | 1 42 | 1 46 | 1 49 | 1 55 |
| December | 1 | 1 14 | 1 14 | 1 18 | 1 21 | 1 25 | 1 27 | 1 29 | 1 31 | 1 33 | 1 36 | 1 40 | 1 44 | 1 47 | 1 52 | 1 57 |
| | 11 | 1 14 | 1 15 | 1 18 | 1 22 | 1 26 | 1 28 | 1 30 | 1 32 | 1 34 | 1 37 | 1 41 | 1 45 | 1 49 | 1 53 | 1 59 |
| | 21 | 1 15 | 1 16 | 1 19 | 1 22 | 1 26 | 1 28 | 1 30 | 1 32 | 1 35 | 1 38 | 1 41 | 1 45 | 1 49 | 1 54 | 1 59 |

*Duration of Civil Twilight. (Interval Between Times When the Upper Edge of the Sun is on and the True Position of Its Centre 6° Below the Horizon.)*

| Date | | North latitude | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0° | 10° | 20° | 25° | 30° | 32° | 34° | 36° | 38° | 40° | 42° | 44° | 46° | 48° | 50° |
| | | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. |
| January | 1 | 22 | 22 | 24 | 25 | 27 | 27 | 27 | 28 | 29 | 30 | 32 | 33 | 34 | 36 | 39 |
| | 11 | 22 | 22 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 31 | 32 | 33 | 35 | 38 |
| | 21 | 22 | 22 | 23 | 24 | 26 | 26 | 27 | 27 | 28 | 29 | 30 | 32 | 33 | 34 | 37 |
| February | 1 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 27 | 27 | 28 | 29 | 31 | 32 | 34 | 35 |
| | 11 | 22 | 22 | 22 | 23 | 25 | 26 | 26 | 27 | 27 | 28 | 29 | 31 | 32 | 34 | 35 |
| | 21 | 21 | 22 | 22 | 23 | 24 | 25 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 32 | 33 |
| March | 1 | 21 | 22 | 22 | 23 | 24 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 31 | 33 |
| | 11 | 21 | 21 | 22 | 23 | 24 | 24 | 25 | 26 | 26 | 27 | 27 | 28 | 30 | 31 | 33 |
| | 21 | 21 | 21 | 22 | 23 | 24 | 24 | 25 | 26 | 26 | 27 | 27 | 28 | 30 | 31 | 33 |
| April | 1 | 21 | 21 | 22 | 23 | 24 | 25 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 32 | 33 |
| | 11 | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 26 | 27 | 28 | 28 | 29 | 31 | 32 | 34 |
| | 21 | 22 | 22 | 22 | 23 | 25 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 32 | 34 | 35 |
| May | 1 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 32 | 33 | 35 | 36 |
| | 11 | 22 | 22 | 23 | 24 | 26 | 27 | 28 | 29 | 29 | 30 | 31 | 33 | 35 | 36 | 39 |
| | 21 | 22 | 22 | 24 | 25 | 27 | 28 | 28 | 29 | 30 | 31 | 33 | 35 | 36 | 38 | 41 |
| June | 1 | 22 | 22 | 24 | 25 | 27 | 28 | 28 | 29 | 31 | 32 | 34 | 36 | 37 | 40 | 43 |
| | 11 | 22 | 23 | 24 | 26 | 28 | 28 | 29 | 30 | 31 | 33 | 34 | 36 | 38 | 41 | 44 |
| | 21 | 22 | 23 | 25 | 26 | 28 | 29 | 29 | 30 | 31 | 33 | 34 | 36 | 38 | 42 | 44 |
| July | 1 | 22 | 23 | 24 | 26 | 28 | 28 | 29 | 30 | 31 | 33 | 34 | 36 | 38 | 41 | 44 |
| | 11 | 22 | 22 | 24 | 25 | 27 | 28 | 28 | 29 | 31 | 32 | 34 | 36 | 37 | 40 | 43 |
| | 21 | 22 | 22 | 24 | 25 | 27 | 28 | 28 | 29 | 30 | 31 | 33 | 35 | 36 | 38 | 41 |
| August | 1 | 22 | 22 | 23 | 24 | 26 | 27 | 28 | 29 | 29 | 30 | 31 | 33 | 35 | 36 | 39 |
| | 11 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 32 | 33 | 35 | 36 |
| | 21 | 22 | 22 | 22 | 23 | 25 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 32 | 34 | 35 |
| September | 1 | 21 | 22 | 22 | 23 | 24 | 25 | 26 | 26 | 27 | 28 | 28 | 29 | 31 | 32 | 34 |
| | 11 | 21 | 21 | 22 | 23 | 24 | 25 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 31 | 33 |
| | 21 | 21 | 21 | 22 | 23 | 24 | 24 | 25 | 26 | 27 | 27 | 27 | 28 | 30 | 31 | 33 |
| October | 1 | 21 | 21 | 22 | 23 | 24 | 24 | 25 | 26 | 26 | 27 | 27 | 29 | 30 | 31 | 32 |
| | 11 | 21 | 22 | 22 | 23 | 24 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 31 | 33 |
| | 21 | 21 | 22 | 22 | 23 | 24 | 25 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 32 | 33 |
| November | 1 | 22 | 22 | 22 | 23 | 25 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 31 | 33 | 34 |
| | 11 | 22 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 31 | 32 | 33 | 35 |
| | 21 | 22 | 22 | 23 | 24 | 26 | 26 | 27 | 28 | 28 | 29 | 30 | 32 | 33 | 34 | 37 |
| December | 1 | 22 | 22 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 31 | 33 | 34 | 35 | 38 |
| | 11 | 22 | 22 | 24 | 25 | 27 | 27 | 28 | 28 | 29 | 30 | 32 | 33 | 34 | 36 | 39 |
| | 21 | 22 | 23 | 24 | 25 | 27 | 27 | 28 | 28 | 29 | 31 | 32 | 33 | 34 | 37 | 39 |

*Relative Illumination Intensities.*

| Source of illumination | Intensity | Ratio to zenithal full moon |
|---|---|---|
| | *Foot-candles* | |
| Zenithal sun | 9,600.0 | 465,000.0 |
| Twilight at sunset or sunrise | 33.0 | 1,598.0 |
| Twilight centre of sun 1° below horizon | 30.0 | 1,453.0 |
| Twilight centre of sun 2° below horizon | 15.0 | 727.0 |
| Twilight centre of sun 3° below horizon | 7.4 | 358.0 |
| Twilight centre of sun 4° below horizon | 3.1 | 150.0 |
| Twilight centre of sun 5° below horizon | 1.1 | 53.0 |
| Twilight centre of sun 6° below horizon (End of civil) | 0.40 | 19.0 |
| Twilight centre of sun 7° below horizon | 0.10 | 5.0 |
| Twilight centre of sun 8° below horizon | 0.04 | 2.0 |
| Twilight centre of sun 8°40′ below horizon | 0.02 | 1.0 |
| Zenithal full moon | 0.02 | 1.0 |
| Twilight centre of sun 9° below horizon | 0.015 | 0.75 |
| Twilight centre of sun 10° below horizon | 0.008 | 0.40 |
| Starlight | 0.00008 | 0.004 |

The foregoing descriptions, which, of course, apply equally to dawn, are by no means universally applicable. Indeed, the sky very commonly is greenish instead of purple, probably when the atmosphere is but moderately dust-laden. Furthermore, the explanations are only qualitative. A rigid analysis, even if the distribution of the atmosphere and its dust and moisture content were known—which they are not, nor are they constant—would be at least difficult and tedious.

*Duration of Twilight.*—The duration of twilight, whether civil, that is, the time after sunset or before sunrise during which there is sufficient light for outdoor occupations, or astronomical, the time until or after complete darkness, varies with the amount of cloudiness and inclination of the ecliptic to the horizon. In the case of clear skies, civil twilight ends, or begins, when the true position of the sun (centre) is about 6° below the horizon, and astronomical twilight when it is about 18° below.

The tables of twilight duration (pages 667 and 668) were computed by Kimball [217] from the equation,

$$h = \frac{\sin \alpha - \sin \phi \sin \delta}{\cos \phi \cos \delta}$$

in which $h$ is the sun's hour angle from the meridian, $\alpha$ the sun's altitude (negative below the horizon), $\delta$ the solar declination, and $\phi$ the latitude.

[217] *Monthly Weather Review*, 44, p. 614, 1916.

*Twilight Illumination.*—The brightness of twilight changes slowly or rapidly, according as the sun is less or more, respectively, than about 4° below the horizon. The following table, based on photometric measurements by Kimball and Thiessen,[218] gives the approximate value of a number of clear-sky, twilight and other natural illumination intensities on a fully exposed horizontal surface.

## CHAPTER VIII.

### PHENOMENA DUE TO SCATTERING: SKY POLARIZATION

THE polarization of sky light, discovered in 1811 by Arago,[219] often is more or less modified by specular reflection from relatively large particles—cloud droplets, coarse dust, etc.—but in general it results from the combination of primarily and secondarily scattered radiation.

*Condition of Primarily Scattered Light.*—As explained by Lord Rayleigh,[220] the light scattered from an incident beam by a gas molecule or other sufficiently small object is symmetrically distributed about the line of enforced motion of that particle as an axis, and completely polarized in the plane at right angles to this line. This follows directly from the fact that plane polarized light is merely light whose vibrations are all normal to the same plane—the plane of polarization. If, then, the incident beam is non-polarized, ordinary sunlight, for instance, the scattered light, therefore, will be completely polarized at right angles to the direction of incidence, and partially polarized in other directions. And, since the plane of polarization is fixed by the sun, observer, and point observed, it follows from Fig. 176 that the ratio

$$\frac{\text{polarized light}}{\text{total light}} = \frac{\sin^2 \gamma}{1 + \cos^2 \gamma},$$

where $\gamma$ = the angular distance of the point observed from the sun. That is, the polarization increases from zero in the direction both of the sun and the antisolar point to a maximum (complete) midway between them, or normal to the incident rays.

*Condition of Secondarily Scattered Light.*—While primary scattering of ordinary light by gas molecules and fine dust par-

[218] *Monthly Weather Review*, 44, p. 614, 1916.

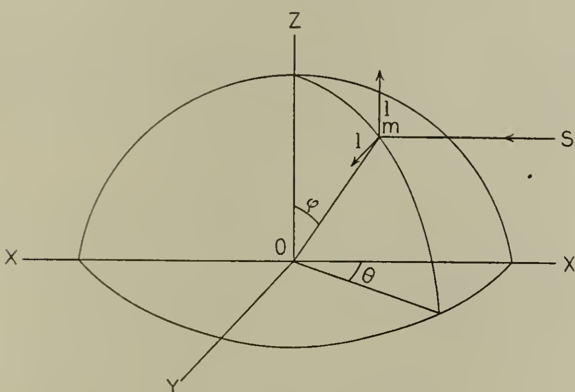
[219] *Astronomie Populaire*, 2, p. 99.

[220] *Phil. Mag.*, 41, p. 107, 1871.

ticles accounts for a large part of the observed polarization and other phenomena of sky light, the non-polarized light that always exists in a greater or less amount at 90° from the sun; the luminosity—partially polarized—of shaded air masses; and the existence of neutral points (small regions whose light is not polarized) are all due, as Soret[221] has shown, to secondary scattering. Tertiary and indefinitely higher scattering obviously also exist, but their effects are too small to justify consideration.

To determine the nature and magnitude of secondary scattering, let $O$ (Fig. 177) be the position of a particle shielded from direct insolation but otherwise exposed, and consider its effect on the total incoming sky light. Let the sun be on the horizon;

FIG. 177.




Intensity of secondarily scattered light.

let $OX$ be parallel to the solar radiation, $OZ$ vertical, and $OY$ normal to the plane $ZX$; let $m$ be any particle a unit distance from $O$; and let $Om$ make the angle $\phi$ with the vertical, and its projection on the plane $XY$ the angle $\theta$ with $OX$.

As the solar rays are non-polarized they may be treated as consisting of two parts of equal amplitude, $l$, say, polarized at right angles to each other. For convenience, let the displacements be parallel to $OZ$ and $OY$, corresponding to polarization in the horizontal and vertical planes, respectively.

On resolving the vertical amplitude into two components, one normal, the other parallel, to $Om$ and the former (which alone is

[221] *Archives de Sci. Phys. et Nat.*, 20, p. 429, 1888.

operative on the particle at $O$) in turn into components parallel to the $X$, $Y$, and $Z$ axes, respectively, one finds that,

$$l'_X = -\, l \sin\phi \cos\phi \cos\theta$$
$$l'_Y = -\, l \sin\phi \cos\phi \sin\theta$$
$$l'_Z = \quad l \sin^2\phi$$

Similarly, on resolving the horizontal amplitude into components normal and parallel to the plane $OZm$, and these in turn parallel to the three axes, one obtains,

$$l''_X = l \cos^2\phi \sin\theta \cos\theta - l \sin\theta \cos\theta = -\, l \sin^2\phi \sin\theta \cos\theta$$
$$l''_Y = l \cos^2\phi \sin^2\theta + l \cos^2 \theta$$
$$l''_Z = -\, l \sin\phi \cos\phi \sin\theta$$

As a crude first approximation let the distribution of the atmosphere about $O$ be equal in all upward directions and assume all parts to be equally illuminated. Further, let $a$ per unit area be the number of particles that, if distributed over the hemispherical shell, would produce at $O$ the same optical effect that actually obtains. Then, the total intensity components at $O$ (found by squaring the amplitudes and integrating over the hemisphere) are given by the equations,

$$I_X = 2\, a\, l^2 \int_0^{\frac{\pi}{2}} \int_0^{\pi} (\sin^2\phi \cos^2\phi \cos^2\theta + \sin^4\phi \sin^2\theta \cos^2\theta) \sin\phi \, d\phi \, d\theta$$

$$I_Y = 2al^2 \int_0^{\frac{\pi}{2}} \int_0^{\pi} (\sin^2\phi \cos^2\phi \sin^2\theta + \cos^4\phi \sin^4\theta + 2 \cos^2\phi \sin^2\theta \cos^2\theta + \cos^4\theta)$$
$$\sin\phi \, d\phi \, d\theta$$

$$I_Z = 2\, a\, l^2 \int_0^{\frac{\pi}{2}} \int_0^{\pi} (\sin^4\phi + \sin^2\phi \cos^2\phi \sin^2\theta) \sin\phi \, d\phi \, d\theta$$

Or,

$$I_X = 2\pi\, a\, l^2 \times 2/15$$
$$I_Y = 2\pi\, a\, l^2 \times 3/5$$
$$I_Z = 2\pi\, a\, l^2 \times 3/5$$

The intensity components of secondary diffusion at the centre of a sphere of uniformly distributed particles would be just twice the above, which, as stated, applies to the centre of a hemisphere.

Since there is an appreciable amplitude along all three of the rectangular axes, it follows that secondary scattering sends

more or less non-polarized light in all directions, and, therefore, prevents sky light from being completely polarized even at right angles to the direction of insolation—the direction of complete polarization by primary scattering.

The above assumption that the light-scattering particles are distributed equally along any upward radius from $O$ obviously is not in close agreement with the actual distribution of the atmosphere and its dust content as visible from any given point in it. Let this distribution be $a(n+1) - a\,n \cos\phi$ particles per unit area of the hemisphere instead of $a$, as previously assumed. Then,

$$Ix = 2\pi a\, l^2 \left[2/15\,(n+1) - 1/16\, n\right]$$

$$Iy = 2\pi a\, l^2 \left[3/5\,(n+1) - 17/48\, n\right]$$

$$Iz = 2\pi a\, l^2 \left[3/5\,(n+1) - 5/24\, n\right].$$

If $n = 12$, that is, if the horizon is 13 times brighter than the zenith—a common condition,

$$Ix = 2\pi\, a\, l^2 \times 0.983$$

$$Iy = 2\pi\, a\, l^2 \times 3.55$$

$$Iz = 2\pi\, a\, l^2 \times 5.3$$

This distribution of intensities still gives non-polarized light in all directions. It also gives a preponderant amount of polarization, $I_z$, in the horizontal plane, which neutralizes at certain places the polarization in the vertical plane due to primary scattering.

The combination, then, of primarily and secondarily scattered light must produce a variety of polarization and other phenomena which necessarily vary with the altitude of the sun, dust content of the atmosphere, and state of the weather. Many observational studies have been made of sky polarization and the facts found to agree with the above theoretical considerations. The principal facts are:

(1) Part of the light from nearly all points in a clear sky is plane polarized, whatever the season, location, altitude of the sun, or other conditions.

(2) The polarized portion of sky light, in turn, is divisible into two parts: (*a*) the positive, due to the first or primary scattering, in which the plane of polarization (plane normal to the

vibrations) is given by the source (sun), point of observation, and eye of the observer; and (*b*) the negative, due to secondary scattering, in which the plane of polarization is normal to that of the primary, and, therefore, because of the ring-like distribution of the atmosphere about any point on the earth's surface, essentially horizontal.

(3) Generally speaking, the percentage of polarized light along any great circle connecting the sun and the antisolar point increases from zero near either to a maximum midway between them, which, in turn, increases with the altitude of the point in question.

(4) The point of absolute maximum polarization is in the solar vertical and ordinarily about 90°, as stated, from the sun.

(5) In general, the percentage of polarization decreases with the amount of light reflected through the sky, whether from the surface or from relatively large particles in suspension. It therefore decreases with (*a*) percentage of snow covering; (*b*) percentage of cloudiness; (*c*) dustiness, or anything that itself leads to an increase of dustiness, such as high winds, especially over arid regions, but everywhere during dry weather, strong vertical convection—hence, generally less during summer than winter—volcanic explosions of the Krakatoa type, etc.

(6) The percentage of polarization generally increases with the wave-length of the light examined.

(7) Even shaded masses of air, if exposed to sky radiation, emit perceptible amounts of polarized light.

(8) Three small regions of unpolarized light, Babinet's, Brewster's and Arago's neutral points, occur on the solar vertical; the first some 15° to 20° above the sun, the second about the same distance below it, and the third 20°, roughly, above the antisolar point.

(9) As the sun rises above or sinks below the horizon the antisolar distance of Arago's point increases from about 20° to, roughly, 23°; while the solar distance of Babinet's point decreases from a maximum of, approximately, 20° to, perhaps, 18°, for a solar depression of 5° or 6°, and to 0°, as does also Brewster's point, as the zenith is approached.

(10) When the upper atmosphere is greatly turbid, as it has often been after violent volcanic explosions, other neutral points, in addition to those above mentioned, are occasionally observed.

*(To be Continued.)*

# THE HIDING POWER OF WHITE PIGMENTS AND PAINTS.*

BY

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THE hiding power of a paint may be defined as that property of a paint which enables it to obliterate beyond recognition any background upon which it may be spread. In order to compare the hiding power of two white pigments, the almost universal custom is to rub down equal masses of the two samples with the same amount of linseed oil and ultramarine blue. The resultant pastes are spread side by side and the sample which has the paler tint is supposed to contain the pigment of greater hiding power. The idea is that the particles of white pigment hide the dark particles and hence give a light tint to the paste. As a result of the experiments to be described presently, it appears that the criterion, upon which the above tests are based, is incorrect.

The object of this investigation is to present a method which will yield numerical values of the true hiding power of white pigments and paints.[1] The basic idea underlying the discussion is this: granting that an infinitely thick layer of a paint will "hide" a given background completely, it is sought to find the thinnest layer which will hide the background as effectively as does the infinitely thick layer. Obviously, the thinner the layer of paint required, the greater is the hiding power of the paint. For white paints, the severest test met with in practice is a white wall with black lettering. It is desired to obliterate the lettering by covering the entire surface with successive coats of paint. These conditions are simulated in the instrument about to be described.

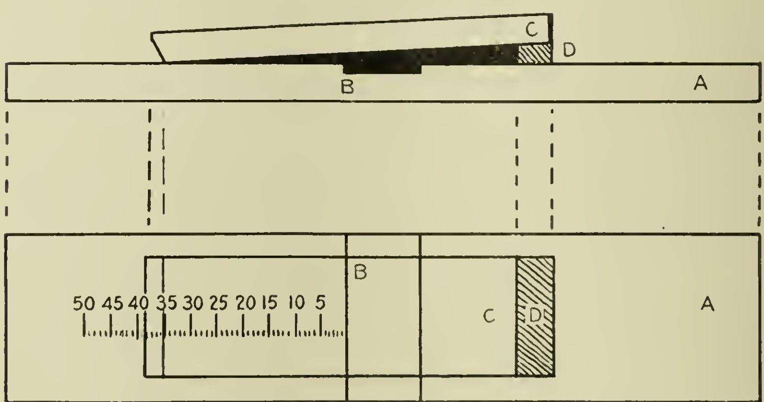
The form given the instrument is shown in Fig. 1. Here, *A* is a plate of glass $14 \times 5 \times .6$ cm. whose upper surface is optically flat. The lower surface is coated with black baking-enamel, which yields the desired black background. A transverse groove, *B*, about 2 mm. deep and 1 cm. wide, is cut in the upper surface and a millimetre scale is etched, as shown in the drawing. Resting upon plate *A* is plate *C* ($7 \times 3.5 \times .6$ cm.), whose lower surface is like-

* Communicated by the Author.

[1] First presented in a report to the New Jersey Zinc Co., Sept. 7, 1918.

wise optically flat. A strip of thin steel, *D,* 0.45 mm. thick, is attached to *C,* so that a wedge-shaped layer of white paint may be formed between the plates. This wedge terminates abruptly at the "infinitely thick" layer, *B,* and, so long as the hiding is not complete, the line of demarcation is visible. By sliding the wedge to the left it is finally impossible to see the edge. From a knowledge of the angle of the wedge and the reading on the scale, it is possible to calculate the thickness of this critical layer lying immediately above the edge *B.* Now, in advancing the plate *C* until the line of demarcation can no longer be seen, we have overdone it, so to speak. To correct this, we must reverse the motion of the wedge until the edge can just be distinguished over its entire length. The mean value of the reading corresponding, respec-

FIG. 1.



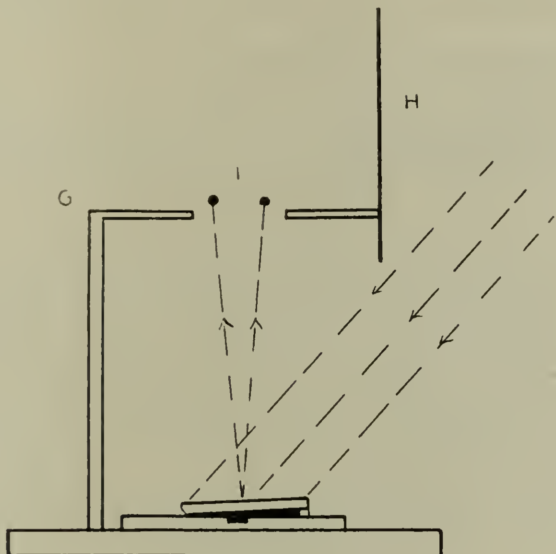

tively, to disappearance and appearance of the edge, yields the desired result. Since the fading away and reappearance is so gradual, due to the fact that the least perceptible increment of intensity which the human eye can detect is 1 to 2 per cent. (Fechner's Law), it is clear that no high degree of precision is attainable by this method. By taking ten pairs of readings it is found that the average deviation from the mean is about 3 to 4 per cent.

A suitable viewing device has been found necessary since the reflection of the observer's face in the plate *C* is annoying. An advantageous arrangement is shown in Fig. 2, where strong daylight illuminates the apparatus from the observer's right (or left). The essentials of the device are, a blackened board, *G,* about 30 cm. above the apparatus, with suitable openings for the eyes, *I,*

and a vertical blackened shield, *H*. The entire instrument is to be called "Cryptometer."[2] (κρύπτω conceal; μέτρον measure).

If it should ever become necessary to develop the instrument so as to yield results of high precision it will always be possible to do so. The two methods which suggest themselves are: (1) if we call the hiding complete when the brightness of the variable layer is 99 per cent. of that of the infinitely thick layer, then, by means of a photo-electric cell, which measures the light from the

FIG. 2.




two layers in contact at the edge *B* (Fig. 1), it will be possible to locate the desired point very accurately; (2) by making, preliminarily, a study of the variation of brightness of the paint with increasing thickness, a formula may be established connecting these two quantities; then, by finding a position of the wedge where the brightness is, say, one-half that of the infinitely thick layer, it is possible to calculate the thickness yielding 99 per cent. of the brightness of the infinitely thick layer. These methods have not been developed for the reason that the cryptometer in its present form is not only sufficiently accurate for most purposes but is extremely simple in its construction and operation.

[2] I am indebted to Mr. H. Green for suggesting this name.

A sharp distinction must be made between the hiding power of a pigment and that of a paint. Not only are these quantities expressed in different units, but they are not necessarily related in the sense that a pigment of great hiding power necessarily produces a paint of correspondingly great hiding power. Taking up first the hiding power of pigments, let us consider an intimate mixture of $x$ grs. of a white pigment and $y$ grs. of colorless (or very pale) linseed oil. This mixture is tested in the cryptometer and the critical thickness producing complete hiding is found. Let

$t$ = thickness of critical layer (in cms.).

$b$ = numbers of grs. of pigment in a disc of 1 cm.$^2$ base and thickness $t$.

Then, if $b$ grs. pigment hide 1 sq. cm., we find the number of sq. cm. $A$ covered and hidden by 1 gr. of pigment from the relation

$$b : 1 :: 1 : A \text{ or } \frac{1}{b} = A.$$

Since the hiding power is better the thinner the layer, *i.e.*, smaller than $b$, we may define the hiding power of a pigment as the reciprocal of the number of grs. of pigment, mixed with colorless linseed oil to painting consistency, which are necessary to hide a black, non-absorbent area 1 cm$^2$. This is numerically equal to the number of square centimetres covered and hidden by 1 gr. of pigment. Hiding powers of pigments will, therefore, be expressed in terms of cm$^2$. per gr. Experiment has shown that the hiding power of the pigment is affected by the relative amount of oil present—the thinner the mixture, the greater the hiding power. This means that the hiding power is not only a function of the number of white particles, but also of their separation. In order to reduce all mixtures to a standard condition, the terms "painting consistency" are specified in the above definition. Data will be presented later.

Turning next to the hiding powers of paints, we choose, as a measure, the number of sq. ft. which one gallon of paint will cover and hide. While the retention of the metric system might, at first thought, seem advisable, practice dictates the selection of the English system of units. The actual measurements and calculations are very simple. The paint is measured up in the cryptometer and, from a knowledge of the critical thickness, the number of square feet per gallon is calculated at once. As a matter of fact, cryptometers are now made so that one may read the result directly off a separate scale etched on the lower plate.

The results obtained for characteristic pigments and paints are summarized in the following table:

| Pigment. | grs. pigment / grs. oil. | Hiding-power pigment. | Hiding-power paint. |
|---|---|---|---|
| | | $\frac{cm^2}{gr.}$ | $\frac{sq.\ ft.}{gal.}$ |
| 1. Sublimed white lead | 7:3 | 26 | 172 |
| 2. Basic carbonate white lead | 7:3 | 36 | 243 |
| 3. Lithopone | 4:3 | 51 | 190 |
| 4. Titanox | 3:4 | 58 | 132 |
| 5. Zinc oxide (leaded) | 1:1 | 59 | 194 |
| 6. Zinc oxide (pure) | 3:4 | 57 | 145 |
| 7. Zinc oxide plus trace of lamp black | 3:4 | 190 | 486 |

Concerning the pigments themselves, the results obtained speak for themselves. The theory of hiding power as dependent on particle size, wave-length of light, character of vehicle, etc., will be taken up in a separate paper. The one point, however, to which attention must be called, is that involving a comparison of pigments 6 and 7. The only difference between these two pigments is that 6 is white while 7 is pearl gray. If these same pigments are compared by rubbing them down with oil and ultramarine blue, the gray sample will show the darker tint; hence it will be considered as having a smaller hiding power than the white sample. As a matter of fact, the hiding power of the gray sample is more than three times as great as that of the white. In a paper describing a new colorimeter,[3] it will be shown that all paints are more or less gray. It is, therefore, clear that, since the rub-down test yields results which are violently at variance with those obtained with the cryptometer, the former method must be discarded.

The results on paints are interesting. While the hiding powers of zinc pigments are larger than those of the white leads, the reverse is true of the paints. (Compare samples 2 and 6.) The reason is obvious when the "oil absorption" of the pigments is considered. One pound of zinc oxide mixed with one pound of linseed oil yields a mixture of proper painting consistency, while a similar mixture of white lead in oil is entirely too "runny" for painting purposes. More lead must be added to give the correct "body" or thickening to the paint. Such a paint has the greater

[3] Presented at the fall meeting of the National Academy of Sciences, Baltimore, 1918; also at meeting of the Optical Society, Baltimore, Dec. 28, 1918.

hiding power, but it has gained its superiority in consequence of the excess of lead pigment which has been added.

While ideal conditions exist in the cryptometer tests, it seemed of interest to compare the results thus found with those obtained in actual painting practice. I am indebted to Mr. R. J. Hauk for preparing the paints and carrying out the painting tests. Briefly, the experiment consisted in preparing three zinc paints (pigment ground in linseed oil). Three clapboard panels, having an area of 3.75 square feet, were well primed with white paint. A cross of black paint was applied to each of these surfaces and the whole was allowed to dry. Then successive coats of the respective paints were applied until the black cross could no longer be seen. From a knowledge of the area painted and the volume of paint consumed in each case it was possible to calculate the number of square feet per gallon which the respective paints would cover and hide. These tests extended over a week or more. When about half the adequate number of coats had been applied, the writer made hiding-power tests with the cryptometer. The results were as follows:

| Paint. | No. of coats. | Hiding-power painting test. $\frac{\text{sq. ft.}}{\text{gal.}}$ | Hiding-power cryptometer. $\frac{\text{sq. ft.}}{\text{gal.}}$ |
|---|---|---|---|
| 1. ZnO (heavily leaded)..63.2 per cent.<br>Vehicle..............36.8 per cent. | 6 | 225 | 256 |
| 2. ZnO (less heavily leaded) 52.7 per cent.<br>Vehicle................47.3 per cent. | 7 | 204 | 213 |
| 3. ZnO (pure)...........48.6 per cent.<br>Vehicle..............51.4 per cent. | 9 | 150 | 150 |

On the whole, the agreement is quite good. The findings of the painting test will always be the smaller for two reasons:

1. Brush marks will leave thin places which must be covered up.

2. Only whole numbers of coats may be applied, *i.e.*, if theoretically 6.4 coats would just hide the black cross it is unavoidable that 7 coats be applied. Obviously, the greater the number of coats, the closer is the approach to the ideal conditions which are realized in the cryptometer.

The conclusion to be drawn from these experiments is that the true hiding power of a paint may be obtained in a very few minutes by means of the cryptometer.

It is clear that if a surface of lighter tint (say, white pine) is to be hidden, the number of square feet per gallon will be considerably larger. The cryptometer must necessarily leave out of consideration the absorption of the paint in the pores of the wood. However, this instrument may be adapted to take care of lighter backgrounds by removing the black paint from the lower surface of plate (*A*), Fig. 1. If this plate be rested on the actual surface to be painted, it is again possible to determine in advance just how many gallons are required to paint a given area.

The principal purpose of this discussion is to present the cryptometer rather than final values of the hiding power of pigments and paints. In order to realize the latter, it will be necessary to grind the pigments in oil and to formulate a rigorous definition of, and test for, " painting consistency."

The results obtained may be summarized as follows:

1. An instrument which yields numerical values of the hiding powers of pigments and paints has been devised.

2. A table of true hiding powers of characteristic pigments and paints is presented.

3. A comparison of actual painting and cryptometer tests shows that the two are essentially in agreement.

(This work was carried out partly at the Johns Hopkins University and partly at the Research Laboratory of the New Jersey Zinc Co.)

September 30, 1919.

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**Helium Production in the United States.**—Bulletin 178*c*, being part of the advance sheets of Bulletin 178, about to be issued by the Bureau of Mines, gives at some length the work that was done during the war in the search for sources and methods of extraction of helium. No more romantic story is likely to be developed in connection with the labors of the Chemical Warfare Service and War Industries Board than that set forth in this account. The value of helium is simply, that being uninflammable and next in lightness to hydrogen among known substances, it serves excellently for balloons.

Even in the discovery of helium there is a most interesting romance which serves to show the connection between the most important and even tragic phases of life and pure research. Helium was first recognized in the sun and for a long while no terrestrial occurrence was known. In 1868 Janssen observed a yellow line in the spectrum of the solar chromosphere, near, but not coincident with, the sodium lines. In 1889 Hillebrand noticed the evolution of inert gases from uraninite, which he supposed to

be an alltropic form of nitrogen. In fact, these gases do contain nitrogen, but it remained for Ramsay and Crookes, operating with cleveite, a variety of uraninite, to obtain a gas which gave the same line that Janssen had observed. Frankland and Lockyer, who had followed up Janssen's work, had given the name "helium" to the substance causing the line.

It was soon found that helium is widely distributed on the earth but in small amounts. It has been proved to be the end-product of the emanations of radio-active substances. In 1915 Ramsay wrote to Moore, of the Bureau of Mines, stating that he had been endeavoring to find sources of helium for use in air-ships, but had found none in England. He stated that he would obtain samples of mine and other natural gases from Canada and the United States. As the United States was then a neutral country, no special attention was paid to the subject, but Moore recalled that in 1907 Cady and McFarland had published a paper in the *Jour. Amer. Chem. Soc.*, showing the presence of helium in natural gas from Kansas. The subject became of great importance in 1917, when the United States entered the war, and many experts were consulted with a view to securing sources of helium and methods of obtaining it in quantity. These efforts are described in much detail in the bulletin, among which is the information that in the summer of 1917 Dr. R. B. Owens, Secretary of The Franklin Institute, then a captain in the Signal Service Corps, was sent abroad on a special mission, but being much interested in the helium problem he took with him a special letter to the British Admiralty, which resulted in the sending of two British naval officers to investigate the subject.

The ultimate result of the efforts of the many experts and civil and military officials was that large amounts of nearly pure helium were obtained from natural gas. At the time the armistice was signed, about 200,000 cubic feet of gas containing 92.5 per cent. of helium had been produced and stored in steel cylinders under 2000 pounds' pressure. Seven hundred and fifty of these cylinders, each containing enough gas to make 200 cubic feet at atmospheric pressure, were on the dock at New Orleans ready for shipment to France, when the cessation of hostilities occurred.

H. L.

**The Electric Furnace Defended.** H. G. WEIDENTHAL. (*American Electrochemical Society*, 1919.)—A polemic defending the electric furnace for steel-making against prejudices of the trade. The user is urged to acquaint himself thoroughly with electric furnace practice and furnish the best that can be produced by the electric furnace. Thus "he will do justice to himself and his business, and at the same time give the electric furnace a square deal."

# DEVELOPMENT OF AN AIRCRAFT INCIDENCE METER.*

BY

A. F. ZAHM, Ph.D.

Navy Department, Bureau of Construction, and Repair.

*Preface.*—To enable the air pilot to read at a glance the direction of flow of the air past his airship or airplane, a balanced weathervane indicating promptly small changes of incidence has been developed and tried under regular working conditions. The scale drawings and test of the device herein described were made respectively by Mr. L. H. Crook and Mr. S. S. Rathbun, members of the aeronautics staff at the Washington Navy Yard.

FIG. 1.

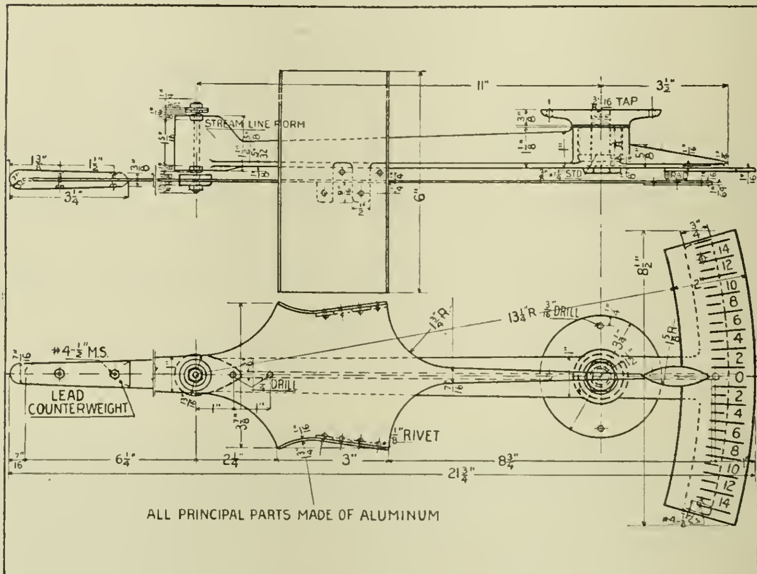

Aircraft incidence meter.

*Model.*—Figs. 1 and 2 give the general appearance and dimensions of this instrument. It consists of a two-blade weathervane supported on a horizontal pivot at the end of a bracket arm protruding forward from an airplane strut and adjustable in pitch by means of the clamping nut at its base. The vane has a forward counter-weight to insure static balance, and a pointer playing on a graduated arc of fourteen inches radius, indicating even degrees

* Communicated by the Author.

and readable to fractions of a degree from the pilot's seat. The blades have the sectional shape of an Eiffel Wing No. 5, which at zero incidence possesses very slight drag and a large increase of lift with slight increase of incidence.

FIG. 2.




Plan for aircraft incidence meter.

*Wind Tunnel Test.*—When the instrument was given its preliminary test in the $8' \times 8'$ tunnel its pointer remained steadily fixed in the wind direction until forcibly displaced. It then promptly returned to zero incidence without lag or indication of friction.

*Observations with C. & R. Incidence Meter in Flight.*

| Speed of Flight in Knots | 55 | 65 | 75 |
|---|---|---|---|
| Normal variation . . . . . | ± 0.6° | ± 0.4° | ± 0.4° |
| Precision of reading possible . . . . . . . . . . | ± 0.3° | ± 0.2° | ± 0.2° |
| Occasional variation . . | ± 2.° | ± 1.° | ± 1.° |

*Test in Flight.*—The instrument was finally mounted midway between planes on the nearest right-hand strut of Flying Boat HS-2 No. 1840, and carried through very still air at three different fixed speeds. The preceding table indicates its behavior under these circumstances.

*Conclusion.*—If this instrument is to be put into use, it may be lightened somewhat and provided with a strap to lash its flange to the aeroplane strut. So finished, it would weigh about 1.5 pounds.

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**The World's Merchant Tonnage.**—The weekly edition of the *Berliner Tageblatt,* of September 10 last, gives some statistics from the recently published Lloyd's "Register of Shipping," this being the first issue of that maritime text-book published without censorship since the outbreak of the war. The data show that the total merchant tonnage is slightly higher than in 1914, in spite of the great destruction that has been going on, but the distribution under the several flags has been materially changed. In July, 1914, the British flag covered 41.6 per cent. of the total merchant tonnage, the German, 11.1 per cent., and the United States, 9.4 per cent. The American shipping was probably made up largely of the coastwise vessels of the Great Lakes and Atlantic seaboard, with those used in the trade with the West Indies and South America, for the high-seas fleets (the great liners) were mostly under British and German control. In July, 1919, the figures are: British, 34 per cent.; United States, 24 per cent. Germany, of course, has passed into a minor position. The German commentator derives some satisfaction in the case by the view that Great Britain in crushing her closest rival, in pursuance of the "rule the waves" policy, has reared a more dangerous adversary, namely, the United States.

Attention is, however, called by the commentator to the fact that many of the ships now afloat are "old tubs," that would have long since gone to the scrap heap if the scarcity of tonnage had not made use necessary. It is probable, therefore, that in a year or two considerable amortization of tonnage will occur, the replacement coming largely from American and Japanese yards.

H. L.

**Cranes.** Chester C. Rausch. (*National Safety Council,* 1919.)—Ever since Noah handled lumber while constructing the Ark and the Egyptians stones while building the Pyramids, the problem of handling material has been present in industrial work of whatever sort or kind. It is not improbable that one of the earliest methods of handling material was by the use of some form of rope manufactured of hide or woven barks passed over

the limb of a tree. Later some means was found to use parts of trees that had been blown over, or that had in some way been felled, to construct the simpler forms of derricks. As we know them to-day derricks and cranes are the result of a development extending through centuries and representing the solution of many problems one after another. Of late years various forms of power have placed at the disposal of man a ready means for adapting his machines to types of work that were formerly done by the laborious efforts of man and beast.

In no particular field has greater development been made than in that of handling and conveying materials in connection with the process of construction, manufacture, and transportation. More recently the fact that electric current furnishes such a flexible source of power has greatly accelerated this development and in the past decade the enormous increase in the use of steel and iron for the fabrication of structures and objects formerly made of wood has called for a further development of machinery to handle the greater unit weights involved. During the last three or four years particularly the production of cranes of all sorts has increased unbelievably and not only is their lifting capacity greater but their flexibility of operation and their safety of manipulation as well. Where we formerly saw a braced pole derrick superseding a single stick or gin-pole, we now find locomotive cranes, tower derricks, overhead travelling cranes, gantry cranes, floating derricks, wall cranes, gib cranes, and a variety of combinations of these devices that enable almost any conditions where material must be handled to be met by the selection of a type of crane to do the work and that will, at the same time, consume the least power, offer the greatest flexibility, and afford the greatest safety during operation.

**Motor Transport Training Schools.**—The United States Army is definitely launched in the field of vocational training for the motor transport corps. Men skilled in automobile vehicle operation and repair do not exist in anything like adequate numbers for the requirements even of civil life; and the war with Germany has demonstrated that no matter how good our Army may be in other respects, its efficiency will be conditioned by that of the motor transport branch.

Therefore, the Army is organizing schools to train men in the various branches of automobile repair, construction, and operation. There are schools under trained teachers where the time of the pupil is wholly devoted to receiving instruction.

Apart from the military necessity, the automobile industries will benefit by the establishment of this training system.

The United States Civil Service Commission is receiving applications to fill 150 positions of assistant instructors in motor transport training schools.

## NOTES FROM THE U. S. BUREAU OF STANDARDS.*

### AN APPARATUS FOR MEASURING THE RELATIVE WEAR OF SOLE LEATHERS AND THE RESULTS OBTAINED WITH LEATHER FROM DIFFERENT PARTS OF A HIDE.[1]

By R. W. Hart and R. C. Bowker.

[ABSTRACT.]

A SHORT paper dealing with the development of a simple machine for testing the wear resistance of sole leathers and giving the results of extensive research work on the relative resistance to wear in different parts of a bend. The machine, which is described at various stages of its development up to the present time, was designed to subject leather to an abrasive action similar to that which it undergoes on a shoe sole, and to accelerate the wear so that a test could be completed in 24 hours.

The result of three extensive tests on the resistance to wear in different parts of a bend are given, with detailed description of the manner in which these tests were made, one test showing the results of comparative wearing tests both on the machine and in actual service are included in this paper. The results of all investigations show that the laboratory testing machine gives a proper indication of the wearing resistance of leathers.

### EQUILIBRIUM CONDITIONS IN THE SYSTEM CARBON, IRON OXIDE, AND HYDROGEN, IN RELATION TO THE LEDEBUR METHOD FOR DETERMINING OXYGEN IN STEEL.[2]

By J. R. Cain and Leon Adler.

[ABSTRACT.]

IT is shown that mixtures of iron oxide and Acheson graphite are not, and mixtures of iron oxide with "cemented" iron or white iron (annealed or unannealed) are, reduced at 900° C. by

* Communicated by the Director.

[1] Technologic Paper 147.

[2] Scientific Paper 350.

the carbon in them when hydrogen is passed over them at rates of two litres per hour or faster. Because of these facts, it is probably impossible to determine by the Ledebur method more than 75 per cent. of the oxygen present in steels as ferrous oxide. The effect of rate of passage of hydrogen on the Ledebur oxygen content of certain steels is shown.

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## THE COKING OF ILLINOIS COAL IN KOPPERS TYPE OVENS.[3]

By R. S. McBride and W. A. Selvig.

[ABSTRACT.]

(An Operating Test at the St. Paul Plant of Minnesota By-Product Coke Co. Joint Report of National Bureau of Standards and Bureau of Mines.)

The great importance during the war period of substituting Mid-continent coal for coals from more distant sources, even in by-product coke oven work, was well recognized. The Bureau of Standards was ordered to conduct an investigation of a new coke oven process claimed to be especially suited to this purpose and in connection with this the Bureau was requested to conduct a test of the St. Paul plant of the Minnesota By-Product Coke Company which is owned by The Koppers Company, Pittsburgh. The Bureau of Standards, in coöperation with the Bureau of Mines, carried out this operating test, using about 7600 tons of coal from the Orient Mine, Franklin County, Illinois. All phases of coal handling, by-product recovery and laboratory tests were under observation by the staff of 37 Government engineers and chemists employed on the work. In addition, those in charge had the benefit of advice and comment from a considerable number of experts who are specialists in the field of coke oven operation.

The quantity of all coal used and of all by-products obtained was carefully weighed or measured at regular intervals and samples of each material were taken for analysis. The Bureau of Standards was responsible for the general planning and supervision of the test work. Its representatives made all observations of battery operation, high temperature measurements, by-product recovery, and chemical laboratory work on gas and by-products.

[3] Technologic Paper No. 137.

The Bureau of Mines was responsible for the sampling of the coal both as it was loaded at the mine and as dumped at the plant. It supervised the weighing, coal handling, coke handling, and coke sampling operations, and made all analyses of coal and coke. Its representatives also made general observations on the character of the coke and operation of the ovens.

The Minnesota By-Product Coke Company Plant consisted of 65 ovens of 18¼ inches average width, operating during the test period with an average gross coking time of 19 hours and 33 minutes with coal finely pulverized, 12.75 tons per oven as charged. The temperature of the heating wall as determined by rare metal thermocouples averaged about 1200° during the test period. The coke was screened to produce large and small furnace sizes, stove, nut and pea domestic sizes, and breeze. The gas was separated into rich and lean at the battery. Separate test records were kept of each size of coke and of each quality of gas. Practically all of the ammonia produced was made up into sulphate immediately through the direct recovery process. Although the plant operated for the production of pure light oil products only the total production of light oil was measured, but the yield of various constituents was determined by analysis.

The coke produced was very irregular in size, had a longitudinal fracture, was fingery, brittle and shattered easily. The cell structure was very small and regular. The coke was lighter than the average by-product coke, weighing only 23 pounds per cubic foot. The first table summarizes the characteristics and yield of this coke further. The large percentage of domestic sizes obtained and therefore the unusually small percentage of furnace size demonstrates that the coke will not stand handling and screening without breaking up into many smaller sizes. This is due primarily to its fingery and brittle characteristics.

In order to test the behavior of the furnace-size coke produced from the Orient coal, arrangements were made to use about 1800 tons of this material in the blast furnace plant of the Mississippi Valley Iron Company. The coke regularly used at that furnace is produced in Koppers ovens of the Laclede Gas Light Company, St. Louis, from a mixture of Elkhorn, Pocahontas (low volatile) and Illinois coals. The substitution of the Illinois coke for the regular supply was accomplished abruptly and continued without interruption throughout the ten-day period. Several experts were

present during this test, and it was the unanimous opinion of these persons and of the blast furnace operators that the Illinois coke had shown highly satisfactory results. However, it should be borne in mind that the furnace used for this test was of small capacity, and it is not certain, therefore, that the results in this case would be duplicated on a large-size furnace.

The yields of gas and by-products are summarized in the second table.

As a result of the test it is clearly demonstrated that some of the Illinois coals can be coked in the Koppers-type oven without radical change in operating methods for the production of coke which can be successfully used in a blast furnace. However, it appears that the temperature at which Illinois coal should be handled for the production of the best coke is somewhat lower than the best operating temperatures for Eastern coals, and moreover, the speed of coking of the Illinois coal is somewhat less. The yield of gas and by-products from Illinois coal of the kind tested is excellent both in quantity and quality. Of course the coal tested in this case represents one of the best Illinois coals for coking purposes, being lower in ash and sulphur and otherwise superior to many from this field.

In general the comparison of Eastern coking coals with those from the Mid-continent field must be made upon an economic basis since which source will be preferable depends altogether on local conditions which will affect the cost of the material and the relative expense of handling. These phases of the question have, however, not been discussed in this report.

Gas and By-Product Yield Summary.

| Product | Per ton of coal: As charged | Per ton of coal: Dry |
|---|---|---|
| Gas: | | |
| Surplus ........................cubic feet | 5490 | 5970 |
| To ovens ......................cubic feet | 5230 | 5690 |
| Total ..........................cubic feet | 10720 | 11660 |
| Tar: | | |
| As produced ...................gallons | 7.81 | 8.49 |
| Dry (computed) ..............gallons | 7.57 | 8.23 |
| Ammonium sulphate—pure.......pounds | 27.88 | 30.33 |
| Ammonia .......................pounds | 7.19 | 7.82 |

| Light oil: Product | | Per ton of coal As charged | Dry |
|---|---|---|---|
| As produced | gallons | 3.71 | 4.03 |
| Under 200° C. | gallons | 3.11 | 3.38 |
| Benzene | gallons | 2.105 | 2.289 |
| Toluene | gallons | 0.497 | 0.540 |
| Solvent Naphtha | gallons | 0.130 | 0.141 |

COAL AND COKE SUMMARY.

| Coal used | |
|---|---|
| As charged | 7685.6 tons |
| Dry | 7065.4 tons |
| Oven charged | 603 |
| **Coal per oven** | |
| As charged | 12.75 tons |
| Dry | 11.72 tons |
| **Coking time** | |
| Average gross | 19 hr. 33 min. |
| Average net | 19 hr. 11 min. |

| Coke produced (dry) | |
|---|---|
| Furnace | 2704.4 tons |
| Stove | 1178.1 tons |
| Nut | 549.5 tons |
| Pea | 89.9 tons |
| Breeze | 308.4 tons |
| Total | 4830.3 tons |
| **Ratio of dry coke to dry coal** | |
| Furnace | 38.3 per cent. |
| Stove | 16.7 per cent. |
| Nut | 7.7 per cent. |
| Pea | 1.3 per cent. |
| Breeze | 4.4 per cent. |
| Total | 68.4 per cent. |

SIZES OF COKE PRODUCED.

| | |
|---|---|
| Furnace | 56.0 per cent. |
| Stove | 24.4 per cent. |
| Nut | 11.4 per cent. |
| Pea | 1.8 per cent. |
| Breeze | 6.4 per cent. |
| Total | 100.0 per cent. |

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## SOME TESTS OF LIGHT ALUMINUM CASTING ALLOYS; THE EFFECT OF HEAT TREATMENT.[4]

By P. D. Merica and C. P. Karr.

[ABSTRACT.]

THE tensile properties and the hardness of a number of different compositions of light aluminum casting alloys have been determined, the resistance to corrosion compared and the resistance to the action of alternation or vibratory stresses determined on a few commonly used compositions.

It is advisable to use for tensile tests a test bar cast almost to size; a bar cast with the test length $^9/_{16}$ inch in diameter, after-

[4] Technologic Paper No. 139.

wards machined to .505 inch gives satisfactory results. The use of a type of test specimen which can be gripped in a self-centring holder in the testing machine is recommended.

A study of the effect of chemical composition on the mechanical properties has shown that it is possible to obtain an alloy containing from 2 to 3 per cent. of copper together with 1 or 2 per cent. of nickel, manganese or both, which will have a reasonable amount of ductility, and it is believed that an alloy of this type should have commercial value. Tensile properties suggested for such an alloy are the following:

| | |
|---|---|
| Tensile strength | 20,000 to 25,000 pounds per square inch |
| Elongation in 2 inch | not less than 5 per cent. |

The addition of magnesium to alloys containing copper reduces in a marked manner the ductility, but increases the tensile strength and the hardness.

The effect of heat-treatment on test bar castings, consisting of annealing 500° C., cooling them in air from this temperature and allowing them to age for several days, is to increase the tensile strength and the hardness; the ductility of the alloy is generally decreased, but may in some cases be increased. The presence of magnesium in the alloy in amounts of from 0.5 to 1.5 per cent. seems to increase the hardening effect of heat-treatment. The heat-treatment of light aluminum castings would seem to have commercial possibilities.

The microstructure of the different alloys was studied and it was found that fracture in them prefers a path along the brittle envelopes surrounding the grains of aluminum, consisting of the various eutectics which are formed with the added metals or their compounds.

Two months' exposure in the salt spray produced only slight corrosion of several compositions of cast alloys. There was no appreciable difference between the different compositions in resistance to corrosion.

A study of the resistance to the action of alternating stresses of three compositions of light cast alloys:

E series—containing 8 per cent. copper
Z series—containing 2-3 per cent. copper, 12-15 per cent. zinc
G series—containing 1.5-2 per cent. copper, 1.5-2 per cent. manganese,

showed that there was no marked difference in the behavior of the three alloys in the test although the E series was somewhat superior and the G series somewhat inferior to the others. All of the three alloys will withstand 10,000,000 complete reversals (tension to compression) at a maximum fibre stress of 7000 pounds per square inch.

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## AN ELECTROLYTIC RESISTANCE METHOD FOR DETERMINING CARBON IN STEEL.[5]

By J. R. Cain and L. C. Maxwell.

[ABSTRACT.]

METHOD and apparatus are described for rapidly and accurately determining carbon in steel by absorbing in a solution of barium hydroxide the carbon dioxide resulting from direct combustion of the metal in oxygen, and deducing the carbon content from the change in electrical resistance of the barium hydroxide solution.

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## THE DIRECT DETERMINATION OF INDIA RUBBER BY THE NITROSITE METHOD.[6]

By John B. Tuttle and Louis Yurow.

[ABSTRACT.]

THE method of determination of india rubber described by Wesson (Tech. paper 35) was applicable only to compounds containing new rubber, and even for these was not always satisfactory. By varying the procedure, it has been found possible to extend the usefulness of the method to compounds containing reclaimed rubber and substitutes, as well as lamp-black and bituminous substances. The method is based upon the formation of rubber nitrosite, which is purified, burned in a combustion furnace and the carbon dioxide formed is calculated to rubber.

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[5] Technologic Paper No. 141.
[6] Technologic Paper No. 145.

**Magnetic State of Prehistoric Burned Earths.** P. L. MERCANTON. (*Bull. Société Vandoise,* vol. lii, No. 194.)—The author is continuing the investigations of the Italian, Folgheraiter. When pottery was baked or lavas cooled they assumed in many cases a magnetic state depending upon the direction of the earth's magnetic field at the time. If the position which they occupied while cooling can be determined, it is sometimes possible to infer the direction of the earth's magnetic field after a magnetometric investigation of the object. M. Mercanton reports in this paper the results of his examination of eleven pieces of baked clay, used as sinkers in fishing. He finds no regularity of magnetization and concludes that all were baked at a time when the earth's field was horizontal, *i.e.,* when the inclination was zero. He is surprised at this, since the sinkers come from various ages, such as the stone, and the bronze age.

G. F. S.

**Signal Corps School.**—Realizing that there are comparatively few trained radio operators available, to fill the needs of the Signal Corps, the Government has established a training school at Camp Alfred Vail, New Jersey. Here men with only common school education can be sent from the enlisted personnel and secure a thorough training in signal corps specialties. These in the main are the same as one meets in civil life, with the addition of their military application. Men will be trained as telegraph, telephone and radio operators; electricians, instrument makers and repairers; cable splicers, cooks, clerks, photographers; chauffeurs and motorcyclists.

The location of this school at Camp Vail, N. J., will be considered as temporary until the extent of the needs of the Army with reference to permanent Signal Corps Schools has been definitely determined and approved by the War Department.

**Passenger Train Resistance.** (*University of Illinois, Engineering Experiment Station, Bulletin 110,* 1919.)—Tests to determine the resistance of passenger trains at all speeds up to seventy miles per hour, and for average car weights have been completed by the Railway Department of the Engineering Experiment Station of the University of Illinois. Of the 240 cars composing the 28 trains tested, 178 had six-wheel trucks, and 62 had four-wheel trucks. These tests were made on the lines of Illinois Central Railroad by Professor E. C. Schmidt and H. H. Dunn upon well constructed and well maintained main line track laid almost entirely with 85-pound or 90-pound rail and ballasted with broken stone.

From the results, which are given in Bulletin No. 110 of the Engineering Experiment Station, a table has been prepared showing the probable average value of resistance for passenger trains composed of cars weighing from thirty to seventy tons and operating at speeds ranging from five to seventy-five miles per hour.

## NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

### BOTULISM FROM CANNED ASPARAGUS.[1]

By Charles Thom, Ruth B. Edmondson, and L. T. Giltner.

[ABSTRACT]

CANNED asparagus taken from the jar and served as a salad caused the deaths of four persons in Boise, Idaho, in January, 1919. Cultures from a portion of the salad and from one jar of asparagus canned in the same pack as that used in the salad showed a strain of *B. botulinus,* designated for convenience the "Boise strain." Animal experimentation proved that this strain produces a very virulent toxin. Guinea-pigs, rabbits, and chickens are readily susceptible to the toxin when taken by mouth. Cattle, pigs and dogs, while not susceptible to feeding, succumb to injections of the toxin. The strength of the toxin produced by this strain varies with changes in cultural conditions. At the highest toxicity obtained the minimum lethal dose for a guinea-pig weighing from 330 to 400 grams was an intraperitoneal injection of 0.0001 c.c. of a filtered dextrose beef infusion culture incubated 28 days at 35° C.

The toxin is destroyed by heating to 75° C. or by heating at 73° C. for 10 minutes. Bacilli freed from toxin by washing or spores freed from toxin by heat do not produce symptoms of poisoning when fed or injected, but have been recovered from the fæces of fed animals in virulent form. All cultures of this strain have a characteristic offensive odor (putrefactive), which was clearly evident in the canned material connected with this case.

The organism is a heat resistant anærobe, whose optimum temperature is 37° C. It will live and multiply, however, at 12° C. (ice-box temperature). Its spores survive ordinary boiling for an hour or boiling at 10 pounds pressure for 15 minutes. Such an organism, if present, may be expected to survive the heating used in canning and to produce marked evidences of spoilage in the can. When physical evidences of such spoilage are present, the material should be destroyed.

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* Communicated by the Chief of the Bureau.

[1] Published in *J. Amer. Med. Ass'n.*

**Dust Hazard in the Abrasive Industry.**—The conviction is growing among experts, that workers in dusty trades are especially liable to tuberculosis. The subject has been treated in a bulletin by Professor Winslow, of the Yale Medical School, assisted by L. and D. Greenburg of the U. S. Public Health Service and published as Reprint 530 of that service. Extensive examinations were made of two large factories designated respectively as B and C, the former employing 2000 hands, of which 400 are women. In both cases much defect was found in the methods of avoiding dust. While ordinary inspection in one of the factories in which some installations had been made with a view of improving the conditions some benefit appeared, the analysis of the air did not confirm the opinion. Comparisons are given between these factories and those of other occupations in which dust is produced in considerable amount. From the figures it seems that the amount of dust ranges from 2.37 mgms. of solid particles in 100 cubic feet of the air of a good polishing shop, to 780.5 mgms. in the same volume of air in factory C. It is noted that while the total dust in the air of a carpet and blanket mill is higher than most of the other industries given in the table (such as pottery, asbestos, tobacco, steel grinding), the inorganic matter in the textile dust is the lowest. The bulletin concludes with the statement that establishments in which abrasive materials are made may present conditions in regard to aerial dust unequalled in any other industry, and that the subject is an important one in industrial hygiene. It would be worth while to inquire whether any form of gas-mask can be utilized for the protection of the worker.

H. L.

**Heartwood and Sapwood.** (*Technical Notes, Forest Products Laboratory*, 1919.)—In over 300,000 tests which have been made at the Forest Products Laboratory, Madison, Wis., on the various species of wood grown in the United States, no effect upon the mechanical properties of wood due to its change from sapwood into heartwood has ever been noticed. Any difference in the strength of heartwood and sapwood can usually be explained by the growth and density of the wood.

In other than mechanical properties, there are differences between heartwood and sapwood which have an important bearing on their use for various purposes. The sapwood of most American species is considerably less resistant to decay than the heartwood, and where the wood is used without preservative treatment in situations which favor decay, the sapwood is likely to have a much shorter life. In these particular cases, therefore, strength requirements may have an indirect bearing on the choice between heartwood and sapwood, inasmuch as wood infected with decay is likely to have its strength properties, particularly that of shock resistance, greatly reduced.

# THE FRANKLIN INSTITUTE.

(*Proceedings of the Stated Meeting held Wednesday, October 15, 1919.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 15, 1919.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to the membership since last report, 16.

Reports of progress were presented by the Committee on Library, and the Committee on Science and the Arts. The President then announced that the Philadelphia Section of the American Institute of Electrical Engineers was meeting jointly with the Institute, and requested Prof. C. E. Clewell, Chairman, to preside.

Professor Clewell then introduced Captain S. W. Bryant, U. S. N., Acting Director Naval Communication Service, Navy Department, Washington, D. C., who presented a communication entitled "The U. S. Naval Communication Service." The lecture included a description of the formation of the Naval Communication Service and a general outline of its functions; status of this service at the time of the declaration of war and the demands made upon it during the war. Consideration was given to the methods of communication between Naval Headquarters and the fleet and between the fleet and its various units. A description was also given of the high-powered stations and their use during the war, and the development of radio direction finding stations was outlined with an indication of their use in war. Various other activities of the Naval Communication Service were described. The subject was illustrated by lantern slides. After a brief discussion the thanks of the meeting were conveyed to the speaker.

Adjourned.

R. B. OWENS,
*Secretary.*

## COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of the Stated Meeting held Wednesday, October 1, 1919.*

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 1, 1919.

MR. BENJAMIN FRANKLIN *in the Chair.*

The following reports were presented for final action:

No. 2728: Landreth Electrolytic Sewage Process. Protests considered. Howard N. Potts Gold Medal awarded to Clarence P. Landreth of Philadelphia, Pa.

No. 2714: Snook X-ray System. Edward Longstreth Medal of Merit awarded to H. Clyde Snook of New York City.

No. 2729: Simplex Fluid Meter. Edward Longstreth Medal of Merit awarded to John Walter Ledoux of Philadelphia, Pa.

The following report was presented for the first reading:

No. 2743: Raymond Concrete Pile.

R. B. OWENS,
*Secretary.*

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## SECTIONS.

*Mechanical and Engineering Section.*—A joint meeting with the Aëro Club of Pennsylvania was held on Thursday evening, October 2, 1919, Mr. Charles Day and Mr. Joseph A. Steinmetz presiding jointly. Brig. Gen. William Mitchell, Division of Military Aëronautics, War Department, Washington, D. C., presented a communication entitled "The American Air Service at the Front." The speaker described the development of aviation at the beginning of the European War, its progress up to the time the United States entered it, the necessity for basing technical and production development of aircraft and accessories on tactical requirements, conditions that existed from a technical standpoint before the entrance of the United States into the war, the formation of the American Air Service in Europe, its employment, use, tactics it developed and its work in combination with other Air Services. Consideration was also given to the future of the Air Service in this country. The subject was illustrated by numerous lantern slides. The thanks of the meeting were conveyed to the speaker.

Adjourned.

R. B. OWENS,
*Secretary.*

*Section of Photography and Microscopy.*—A joint meeting of the section with the Aëro Club of Pennsylvania was held on October 9, 1919, at 8 o'clock. Dr. Harry F. Keller and Mr. Joseph A. Steinmetz presiding jointly. The paper of the evening, entitled "Photography from the Airplane," was presented by Major Herbert E. Ives, Ph.D., of the Aviation Section, Signal Reserve Corps, lately in charge of Photographic Experimental Work, United States Air Service. The speaker gave an account of the beginning of Photography from the airplane, which occurred at the time of the beginning of the great war, and early became one of the most important activities of all the air forces. By its aid complete detailed maps of enemy trenches, batteries, and lines of communication were always available, thus entirely destroying the factor of secrecy, and so revolutionizing military strategy. Numerous technical problems arose in connection with the methods, apparatus and materials to be used in this newest application of photography, and ultimately nearly every branch of scientific photography lent its aid. The speaker described the research work done for the United States Air Service, and illustrated the subject by

lantern slides of the apparatus used and also exhibited photographs taken over the battle lines. After a vote of thanks to Major Ives the meeting adjourned.

Adjourned.

R. B. OWENS,
*Secretary.*

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## MEMBERSHIP NOTES.

### ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, October 8, 1919.*)

RESIDENT.

MR. G. BERKELEY REED, Inventor, The Gladstone, Philadelphia, Pennsylvania.

NON-RESIDENT.

DR. WILBUR M. STINE, Author, 334 West Main Street, Mechanicsburg, Pennsylvania.

### CHANGES OF ADDRESS.

MR. J. C. BANNISTER, Lock Box 26, Boston, Massachusetts.
MR. CARL G. BARTH, 416 Parkside Avenue, Buffalo, New York.
DR. THOMAS D. COPE, Randal Morgan Laboratory of Physics, University of Pennsylvania, Philadelphia, Pennsylvania.
MR. S. B. ECKERT, Finance Building, 1428 South Penn Square, Philadelphia, Pennsylvania.
MR. HALCOLM ELLIS, 6 Rue de Hanover, Paris, France.
MR. E. L. GIBBS, 2004 Herschell Street, Jacksonville, Florida.
MR. GEORGE R. HENDERSON, 8 West 40th Street, New York City, New York.
MR. JOHN W. HILL, 3536 Mitchell Building, Cincinnati, Ohio.
MR. ANTHONY DEH. HOADLEY, Union College, Schenectady, New York.
MR. P. JUNKERSFELD, Stone and Webster Engineering Corporation, 147 Milk Street, Boston, Massachusetts.
MR. H. J. KREBS, P. O. Box 951, Wilmington, Del.
MR. WM. RICHARD LITTLETON, Merchantville, New Jersey.
MR. JOHN F. McCOY, 3015 Midvale Avenue, Station Z, Philadelphia, Pennsylvania.
MR. JAVIER RESINES, Racquet Club, Philadelphia, Pennsylvania.
MR. FREDERICK W. SALMON, 1129 North 28th Street, Philadelphia, Pennsylvania.
MR. A. B. STITZER, in care of Republic Engineers, Inc., 60 Broadway, New York City, New York.
MR. C. C. TUTWILER, West Conshohocken, Pennsylvania.
MR. J. R. WATKINS, 1920 Vilas Street, Madison, Wisconsin.
MR. ROY V. WRIGHT, 398 North Walnut Street, East Orange, New Jersey.

## NECROLOGY.

**Mr. Charles Norris,** Aldine Hotel, Philadelphia, Pennsylvania.
**Mr. M. C. Smyth,** 1700 Morris Building, Philadelphia, Pennsylvania.

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## LIBRARY NOTES.

### PURCHASES.

BARTLETT, F. W., and JOHNSON, T. W.—Engineering Descriptive Geometry and Drawing. 1919.

FULLER, C. E., and JOHNSTON, W. A.—Applied Mechanics, 2 vols. 1915, 1919.

HELDT, P. M.—The Gasoline Automobile; Its Design and Construction. 3 vols. 1919.

PAGÉ, V. W.—Gasoline and Kerosene Carburetors, Construction—Installation—Adjustment. 1919.

### GIFTS.

Advance Tool Company, Catalogue B. Cincinnati, Ohio, no date. (From the Company.)

Alabama Geological Survey, Bulletin No. 20. University, Alabama, 1918. (From the State Geologist.)

American Cement Tile Manufacturing Company, Booklet of Bonanza Cement Tile Roofing. Pittsburgh, Pennsylvania, 1917. (From the Company.)

Association of Manufacturers of Chilled Car Wheels, Catalogue. Chicago, Illinois, no date. (From the Association.)

Beaumont, R. H., Company, Catalogues Nos. 33, 34, 36, 38 and 41. Philadelphia, Pennsylvania, 1919. (From the Company.)

Bedford Foundry and Machine Company, Catalogue of Cranes and Derricks, no date. (From the Company.)

Benson Electric Company, Catalogue. Superior, Wisconsin, no date. (From the Company.)

Black and Decker Manufacturing Company, Catalogue, 1919. Baltimore, Maryland, 1919. (From the Company.)

Blair Engineering Company, Catalogue of Ports, Valves and Slag Pockets. Chicago, Illinois, no date. (From the Company.)

Blaw-Knox Company, Bulletin No. 200 of Blaw Cableways. Pittsburgh, Pennsylvania, 1919. (From the Company.)

Bradley and Turton, Ltd., Catalogue of Testing Machines. Kidderminster, England, no date. (From the Company.)

Brown, Bayleys Steel Works, Ltd., Catalogue of Die Blocks. Sheffield, England, no date. (From the Works.)

Buckeye Blower Company, Bulletin No. 101. Columbus, Ohio, no date. (From the Company.)

Buffalo Hoist and Derrick Company, Crane Catalogue No. 2 C, and Engine Catalogue No. 21. Buffalo, no date. (From the Company.)

Butterfield and Company, Inc., Catalogue No. 17. Derby Line, Vermont, 1919. (From the Company.)

Canada Department of Mines, Memoir 109. Ottawa, 1919. (From the Department.)

Carnegie Endowment for International Peace, Year-Book, 1919. Washington, District of Columbia, no date. (From the Endowment.)

Central Scientific Company, Catalogue C. Chicago, Illinois, 1919. (From the Company.)

Clapp-Eastham Company, Bulletin Y. Cambridge, Massachusetts, 1919. (From the Company.)

Cleveland Gas Burner and Appliance Company, Booklet of Barber Patented Gas Burners for Artificial and Natural Gas. Cleveland, Ohio, no date. (From the Company.)

Cleveland Milling Machine Company, Catalogue B of Cutters. Cleveland, Ohio, no date. (From the Company.)

Colorado Iron Works Company, Catalogue of Continuous Filtration with the Portland Filter. Denver, Colorado, 1918. (From the Company.)

Cooper Hewitt Electric Company, Bulletin No. 78-B. Hoboken, New Jersey, no date. (From the Company.)

Combustion Engineering Corporation, Bulletin G-1. New York, New York, 1919. (From the Corporation.)

Cornell University, Register for 1918–1919. Ithaca, New York, 1919. (From the University.)

Dayton Electrical Manufacturing Company, Bulletin No. 55. Dayton, Ohio, 1919. (From the Company.)

Dominion of New Zealand, Statistics for the Year 1917, Vol IV. Wellington, 1918. (From the Government Statistician.)

Dorr Company, Bulletin No. 13 of the Dorrco Pump. New York, New York, 1919. (From the Company.)

Earle Gear and Machine Company, Bulletins 71–73, inclusive. Philadelphia, Pennsylvania, no date. (From the Company.)

Electrical Engineers Equipment Company, Bulletin No. 102-A. Chicago, Illinois, 1919. (From the Company.)

Foxboro Company, Inc., Catalogue of Foxboro Thermometers. Foxboro, Massachusetts, 1919. (From the Company.)

Fuller Engineering Company, Bulletin No. 201. Allentown, Pennsylvania, 1919. (From the Company.)

Gifford-Wood Company, Bulletin No. 42. Hudson, New York, 1919. (From the Company.)

Gilbert and Barker Manufacturing Company, Catalogue of Oil Storage Systems. Springfield, Massachusetts, no date. (From the Company.)

Goodrich, B. F., Co., Catalogue of Rubber Hose and Tubing. Akron, Ohio, 1917. (From the Company.)

Grant Manufacturing and Machine Co., Booklet, Perfect Riveting. Bridgeport, Connecticut, 1917. (From the Company.)

Harrison Steel Castings Company, Catalogue of Open Hearth Steel Castings. Attica, Indiana, no date. (From the Company.)

Holcroft and Company, Catalogue describing Ovens and Furnaces. Philadelphia, Pennsylvania, 1919. (From the Company.)

Holden and White, Inc., Catalogue No. 20. Chicago, Illinois, 1919. (From the Company.)

Holz and Company, Inc., Bulletin No. 4. New York, New York, no date. (From the Company.)

Horton, John T., Company, Inc., Catalogue of Winches, Derricks and Cableways. New York, New York, 1919. (From the Company.)

Hydraulic Press Manufacturing Co., Catalogues Nos. 43 and 80. Mount Gilead, Ohio, 1919. (From the Company.)

India Geological Survey, A Bibliography of India Geology and Physical Geography, Parts 1 and 2. Calcutta, 1917–1918. (From the Geological Survey.)

Indian Railway Conference Association, Locomotive and Carriage Superintendents Committee, Proceedings for 1918. Calcutta, India, 1919. (From the Committee.)

Institute of Metals, Journal No. 1, 1919. London, England, 1919. (From the Institute.)

Instituto y Observatorio de Marina, Anales Meteorologicas, Magneticas y Sismicas, Seccion 2. Ano. 1914–1915. San Fernando, Spain, 1915–1916. (From the Observatory.)

International Nickel Company, Catalogue. New York, New York, no date. (From the Company.)

Jewell Belting Company, Booklet, A Study of Various Types of Belting. Hartford, Connecticut, 1919. (From the Company.)

Jones and Lamson Machine Company, Catalogue on Advanced Practice in Machining Pulleys. Springfield, Vermont, 1919. (From the Company.)

Kingsbury Albert, Catalogue of Kingsbury Thrust Bearings. Pittsburgh, Pennsylvania, 1919. (From Albert Kingsbury.)

Knight, W. B., Machinery Company, Catalogue of Knight Milling and Drilling Machines. St. Louis, Missouri, 1919. (From the Company.)

Lakeside Bridge and Steel Company, Bulletins 201–203, inclusive. 1919. (From the Company.)

Liberty Manufacturing Company, Catalogue "Z." Pittsburgh, Pennsylvania. no date. (From the Company.)

Lietz, A., Company, Catalogue of Drawing Materials and Field Equipment. San Francisco, California, 1919. (From the Company.)

Lehigh University, Register 1918–1919. Bethlehem, Pennsylvania, 1919. (From the University.)

Liverpool Engineering Society, Transactions, Vol. XXXIX. 1918. Liverpool, England, 1918. (From the Society.)

Llewellyn Iron Works, Marine Catalogue. Los Angeles, California, 1919. (From the Works.)

Manganese Track Society, Book 8. Chicago, Illinois, 1919. From the Society.)

Marble-Card Electric Company, Bulletin No. 100. Gladstone, Michigan, 1919. (From the Company.)

Mesta Machine Company, Catalogue for 1919. Pittsburgh, Pennsylvania, 1919. (From the Company.)

Michigan State Board of Agriculture and Experiment Station, Fifty-seventh and Thirty-first Annual Reports from July 1, 1917, to June 30, 1918. East Lansing, Michigan, 1919. (From the Board.)

Mine and Smelter Supply Company, Catalogue No. 42. New York, New York, 1918. (From the Company.)

Miner, J. H., Booklet. The Filers' Success. Lumberton, Mississippi, 1915. (From J. H. Miner.)

Munning, A. P., and Co., Bulletin No. 1000. Philadelphia, Pennsylvania, 1919. (From the Company.)

National Pressed Steel Company, Handbook of National Steel Lumber, Massillon, Ohio, 1919. (From the Company.)

Nevada Railroad and Public Service Commissions, Biennial Reports for 1917–1918. Carson City, Nevada, 1919. (From the Commissioner.)

New Mexico State School of Mines, Catalogue 1918–1919. Socorro, New Mexico, 1919. (From the School.)

New York Conservation Commission, Seventh Annual Report for 1917. Albany, 1919. (From the Commission.)

Nuttall, R. D., Company, Catalogues of Heat Treatment of Steel Gears; Pedigreed Gears and The Nuttall Standard Tractor Transmission. Pittsburgh, Pennsylvania, no date. (From the Company.)

Ohio Mechanics Institute, Catalogue 1919–1920. Cincinnati, Ohio, 1919. (From the Institute.)

Ontario Bureau of Mines, Report No. 17, Parts 2 and 3, 1918. Toronto, Canada, 1919. (From the Bureau.)

Ontario Hydro-Electric Power Commission, Eleventh Annual Report, 1918. Toronto, 1919. (From the Commission.)

Osgood Company, Catalogue of Steam Shovels, Clamshell Outfits and Dredges. Marion, Ohio, 1919. (From the Company.)

Over States Machine Co., Inc., Catalogue, Electric Controlling and Starting Devices. New York City, New York, 1919. (From the Company.)

Patch, F. R., Manufacturing Company, Catalogue K. Rutland, Vermont, no date. (From the Company.)

Pelton Water Wheel Company, Bulletins Nos. 11 and 12. San Francisco, California, 1919. (From the Company.)

Queensland Department of Mines, Annual Report of the Under Secretary for the Year 1918. Brisbane, 1919. (From the Department.)

Roach, Joseph H., and Company, Catalogue, The Roach Stoker. Philadelphia, Pennsylvania, no date. (From the Company.)

Rogers and Hubbard Company, Booklet How to Case-Harden Color and Anneal with Granulated Raw Bone. Middletown, Connecticut, no date. (From the Company.)

Roots, P. H. and F. M., Company, Catalogues Nos. 63 and 68. New York City, New York, no date. (From the Company.)

Ross Heater and Manufacturing Company, Catalogue C. Buffalo, New York, 1919. (From the Company.)

The Shoe and Leather Reporter Company, Annual Directory, 1919. Boston, Massachusetts, 1919. (From the Company.)

Smalley-General Company, Inc., Catalogue, Fundamentals of Thread Milling. Bay City, Michigan, no date. (From the Company.)
Smith, Werner G., Company, Booklet, The Chemistry of a Core. Cleveland, Ohio, 1919. (From the Company.)
South Bend Lathe Works, Lathe Book No. 19, Catalogue No. 57. South Bend, Indiana, 1919. (From the Works.)
Star Brass Works, Bulletin No. 5. Chicago, Illinois, 1919. (From the Works.)
Stuebing Truck Company, Catalogue. Cincinnati, Ohio, no date. (From the Company.)
Tennessee Railroad Commission, Report for the Years 1917–1918. Nashville, Tennessee, 1918. (From the Commission.)
Traylor Engineering and Manufacturing Company, Catalogue of Bulldog Jaw Crushers. Allentown, Pennsylvania, 1919. (From the Company.)
Trimount Rotary Power Company, Booklet of Trimount Rotary Pumps. Boston, Massachusetts, 1919. (From the Company.)
United States Crane Company, Bulletin No. 190. Chicago, Illinois, 1919. (From the Company.)
University of British Columbia, Calendar, Fifth Session, 1919–1920. Vancouver, British Columbia, 1919. (From the University.)
University of Utah, General Catalogue 1919–1920. Salt Lake City, 1919. (From the University.)
Wallace Barnes Company, Booklet of Springs and Screw Machine Products. Bristol, Connecticut, 1916. (From the Company.)
Whiting Foundry Equipment Company, Catalogue No. 145. Harvey, Illinois, 1919. (From the Company.)
Winget, Ltd., Catalogues of the Winget Pressure Machine; The Winget Chain-Spade and the Winget Concrete Block and Slab Making Machine. London, England, 1919. (From the Company.)
Wood, R. D., and Company, Catalogue, The Automatic Gas Producer. Philadelphia, Pennsylvania, no date. (From the Company.)
Vulcan Soot Cleaner Company, Bulletin No. 451. Du Bois, Pennsylvania, 1919. (From the Company.)

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## BOOK NOTICES.

COBALT: ITS OCCURRENCE, METALLURGY, USES AND ALLOYS. Report of the Ontario (Canada) Bureau of Mines, 1918, vol. xxvii, Part III, Section 1. Prepared by Charles W. Drury. 122 pages and Index, 8vo. Toronto, 1919.

Cobalt has always been numbered among the rather rare metals, and its practical uses have been limited by that fact. According to the report at hand, only five locations are known at which cobalt ores are either being worked or suitable as sources. These are, respectively, in Ontario, Missouri, New Caledonia, Belgian Congo and Schneeberg, Germany. The Ontario deposits, at Cobalt, are the largest. The shipping ore and concentrates contain an average of 7 to 10 per cent. of the metal, 5 per cent. of nickel, 25 per cent. of arsenic, and from 300 to 1000 ounces of silver per ton. As might

be expected from the large amount of arsenic, the cobalt and nickel occur principally as arsenides. Arsenic and silver are not found with the Missouri ores, which are of an entirely different class from the Canadian, containing copper and lead, and much smaller averages of cobalt and nickel. The new Caledonian ore is chiefly oxide, averaging about 3 per cent. The mines of the Belgian Congo yield an ore containing much copper and about 3 per cent. of cobalt. The Schneeberg ores are also poor in nickel and cobalt, but richer in bismuth.

The total world production is about 500 tons per year. The Canadian deposits will be the most prolific source for some years, but the production of the Missouri mines will probably suffice for the needs of the United States. The New Caledonia mines are not active on account of the high cost of transportation.

Over twenty species of minerals containing cobalt as a definite ingredient are described in the pamphlet, and the geology and mineralogy of the deposits in the several localities are extensively treated.

The production of the several metals from the mines at Cobalt, Canada, in 1917, was as follows:

| Metal | Tons | Value in Dollars |
|---|---|---|
| Nickel | 155 | 125,071 |
| Cobalt | 337 | 1,138,190 |
| Arsenic | 2,592 | 608,483 |

In addition, 19,401,893 ounces of silver, valued at $16,121,013 were mined. The arsenic is presumably given in the form of arsenous oxide. The total value of the product of the mines during 1917 was $18,028,597.

The uses of cobalt are treated in a special chapter. These were used originally largely in the enamel, porcelain and glass industries, but new uses have been found of late years, among which is an alloy of cobalt and chromium known as "stellite," used in the manufacture of cutting tools. The metal is also added to some high-speed steels. A limited amount of cobalt plating is carried out. The use of cobalt compounds as coloring agents is of great antiquity.

A large amount of space is given to descriptions of the alloys of cobalt with elaborate metallurgic and physical data according to the recent methods in physical chemistry. The pamphlet is well printed and well illustrated.

HENRY LEFFMANN.

THE CONDENSED CHEMICAL DICTIONARY. Compiled and edited by the Editorial Staff of the Chemical Engineering Catalog; F. M. Turner, Jr., Technical Editor; D. D. Berolzheimer, W. P. Cutter and John Helfrich, Assistant Editors. 525 pages, 8vo. New York, The Chemical Catalog, Inc., $5.00 net.

A very large amount of interesting and valuable information is contained in this book. It is almost entirely concerned with the chemical substances used in practical work. Terms in theoretical chemistry are not within its

field. Its scope and method can be best set forth by a brief statement of the treatment of a given item. Opening at random, the reviewer finds on page 54, "Alizarin." The word is starred to show that the substance is now made in the United States. Its systematic name and rational formula are given; the color, melting and boiling points and, in general terms, solubility in alcohol, water and ether. A brief account is then given of the method of preparation. The commercial grades, the material used for containers, the fire hazard and the railroad shipping regulations are stated. In this particular case we learn that there is no fire hazard and the shipment is not specifically controlled. The applications of the "red" "yellow" and "green" labels are indicated whenever necessary. Useful tables of equivalents of Fahrenheit and centigrade scales, and of atomic weights (o = 16 basis), and for converting Baumé degrees into specific gravities, are given; also several pages of definitions of units in the several departments of applied science.

The make-up of the book is excellent—good paper, good type and printing and strong binding. Those engaged in the preparation of the text deserve much praise, and the work will be of great service to practical chemists.

As a second edition of the book will be soon demanded, the reviewer ventures to suggest a further "condensation." Could not melting and boiling points be just as clearly indicated by "b.p." and "m.p."? In many cases the method of manufacture might be omitted, as it is usually too briefly given to be of any practical value. The repetition of titles such as "color," "fire hazard," "railroad shipping regulations," seems unnecessary. As an illustration of the reviewer's idea of condensation, the description of "Nitric Acid" may be considered. This occupies nearly half a page. By condensing such terms as "specific gravity" to "sp. gr." and the other abbreviations just mentioned and omitting the outline of the processes of manufacture, which are much too briefly described to be of any value to the practical worker (elaborate descriptions of such processes are in standard works), a great saving of space could be secured. This would enable a much larger list of substances to be included, and thus increase the usefulness of the volume.

It will be a great convenience to works chemists and commercial analysts to have in compact form and at a reasonable cost such a large amount of information on the properties and composition of commercial chemicals.

HENRY LEFFMANN.

## PUBLICATIONS RECEIVED.

*How To Do It:* A book of "kinks" from the magazine *Concrete*. Compiled by Harvey Whipple, Managing Editor, *Concrete*. 143 pages, illustrations, 12mo. Detroit, Mich., Concrete-Cement Age Publishing Company, 1919.

*Technical Books of 1918:* A selection. 28 pages, 12mo. Brooklyn, N. Y., Pratt Institute Free Library, 1919.

*U. S. Bureau of Mines:* Monthly Statement of Coal Mine Fatalities in the United States, July, 1919, compiled by Albert H. Fay. 24 pages, 8vo. Technical paper 239. Coke Oven Accidents in the United States During the Calendar Year 1918, compiled by Albert H. Fay. 26 pages, 8vo. Washington, Government Printing Office, 1919.

*U. S. Bureau of Standards:* Scientific paper No. 341. Airplane Antenna Constants, by J. M. Cork, assistant physicist. 15 pages, illustrations, 8vo. Washington, Government Printing Office, 1919.

*Representation in Industry*, by John D. Rockefeller, Jr. Address before the War Emergency and Reconstruction Conference of the Chamber of Commerce of the United States, Atlantic City, N. J., December 5, 1918. 31 pages, 12mo. No place of publication.

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**The Piezo-electric Effect, a New Principle for Telephone Transmitters and Receivers.** A. M. NICHOLSON. (*Session of the Am. Inst. Elec. Engs.,* October 10, 1919.)—When certain crystals are compressed in definite directions a difference of potential is developed between their ends. Conversely, when a difference of potential is applied to the same crystals, they elongate or contract. Similar effects are observed when the crystals are in a condition of torsion. This general effect gives a means of converting mechanical energy into electrical energy and *vice versa.*

The crystals showing the above effect are hemihedral or hemimorphic. Those of Rochelle salt are especially good and large specimens can be grown. Under torsion such crystals give a difference of potential of as much as 600 volts. Desiccated crystals are several times as effective as freshly prepared ones.

The method of transmitting sound is as follows: A crystal under torsion that the motion of the stylus of a phonograph varies the strain already existing and hence develops a difference of potential between the two ends. Two wires are led from the crystal to a 3-stage amplifier to the other end of which is electrically connected a second crystal, likewise under torsion. The varying potential supplied from the amplifier causes the crystal to dilate and to contract. These motions which closely follow the intricate motion of the stylus cause air-waves. Instead of the stylus the human voice may be used directly to vary the force acting on the transmitting crystal.

A demonstration of this very significant method of sound transmission was given in the Bellevue-Stratford Hotel, Philadelphia, October 10, 1919. The voice of a man by "direct action" as well as instrumental music and the voice of Galli Curci from phonograph records were well rendered. The effect was especially good when the receiving crystal was placed on a bare wooden table. It was not even necessary to press the crystal upon the supporting surface. The quality of the sounds produced was good.

This was the first public exhibition of the new means of transmission and was made only about three days after success had been attained in the laboratory.

G. F. S.

# CURRENT TOPICS.

**The Industrial Value of Mosquito Prevention.**—It seems a far cry from the "Promotion of the Mechanic Arts" to the study of the life history of the mosquito, but research has left no reason to doubt the serious injury that this insect can and does do to human beings. In this part of the world malaria and yellow fever are the two diseases which are known to be propagated only by the direct agency of this class of insects. The former is now reduced to minor importance by the thorough measures that have been employed in tropical and sub-tropical countries, but malaria is still a most serious cause of ill-health and consequent loss of efficiency in young adults. No subject is attracting more attention nowadays than industrial hygiene, which in its broadest sense, covers all phases of disease and injury whether directly or indirectly the result of occupation.

Sanitarians have leaned to the view that mosquitoes specialize, so to speak, as disease carriers; that is, one species carries yellow fever and another malaria. *Anopheles punctipennis* has been generally charged with the conveyance of the several forms of malaria, but evidence has been adduced that another species (*A. crucians*) can act as an infection agent. The data are given in a bulletin (Reprint 536 from U. S. Public Health Service Report) by Dr. C. W. Metz. It does not appear that this species is as active as the species above mentioned, as it is apparently an out-of-door biter, not being inclined to enter houses at night. If its infecting power is established the necessity for screening of porches and outhouses will be evident.

In this connection, mention may be made of some experiments carried out under the auspices of the U. S. P. H. Service, by S. F. Hildebrand, Ichthyologist of the U. S. Bureau of Fisheries, to determine the value of fishes as destroyers of mosquito larvæ. The experiments were undertaken in the extra-cantonment zone of Camp Hancock, Augusta, Ga., as a hygienic measure, inasmuch as the district included a large number of shallow collections of water which would serve as mosquito breeding grounds. Many of the collections were drainable, but some were not amenable to this treatment, nor to oiling. The investigation continued from March, 1918, to November, 1918. Several fishes have been suggested as anti-mosquito agents, but Hildebrand limited his work to the common top-minnow (*Gambusia affinis*), which is so well known and so much used as a bait for larger fish. Indeed, this use for bait was one of the interferences with the work, and had to be formally forbidden.

After giving an account of the physio-geographic conditions of the region and the methods of introducing the fish, the results are stated and the following are some of the conclusions: The top-minnow is especially suitable for anti-mosquito work, as it seeks its food at the surface (where the larvæ are), is very prolific, giving birth to well-developed young, and therefore requiring no special hatching or breeding environment; lives and thrives under a wide range of conditions, most of which are especially liable to be mosquito breeding grounds. It can live and multiply in ponds containing predacious fishes, if there is shallow water into which it can escape.

An interesting experiment occurred accidentally. On March 29, a pond was found to be fairly alive with mosquito pupæ and larvæ, but fish not present. Minnows were placed in the water, but all died in less than an hour. The pond was near a sulphuric acid factory. Litmus paper showed strong acid reaction in the water. It appears, therefore, that mosquito larvæ can live in water promptly fatal to fish.

Doctor Metz has also investigated the food of the anopheles larvæ and found that this creature is practically omnivorous, but that it does not thrive in water much fouled with decomposing organic matter. This serves to show that if sloughs and stagnant pools are cleaned, subsequent provision must be made for draining, oiling, fish control or some other method of mosquito eradication.

H. L.

Interesting Technical Exhibits. (*Nature*, July 10, 1919.)—Of especial interest at the British Scientific Products Exhibition in July of this year are these: Apparatus for testing screw-thread gauges by optical projection; a 30-foot range-finder by which a range of 10,000 yards can be signalled to the gun in less than three seconds with an error of twenty-one yards; stages in the development of the airplane, all of metal; model of the largest armor-piercing shell, 18-inch calibre, weighing 1½ tons. In connection with this exhibition Prof. W. H. Bragg lectured on the detection and the transmission of sounds in water. A "hydrophone" was shown which has a diaphragm carying a microphone. On one side the diaphragm is screened against sound waves, while the other side receives them. The vibrations of the microphone are recorded graphically. If a number of stations are equipped with hydrophones and an explosion is produced in the water, the waves will reach the several stations at different times, and from these data and the known speed of sound waves in water the place of the explosion can be worked out, as is done in sound-ranging in air. The method has been applied to distances as great as 230 miles. Thus an additional means of locating ships has been devised.

Another lecture at the exhibition was by H. E. Armstrong on "Coal Conservation," in which he advocated the prohibition of

the use of raw coal in order to substitute the use of smokeless fuel, not only to avoid the smoke but also to save the volatile products. He advised the establishment of large centres of combustion, where the by-products would be utilized and maximum economies perfected. For domestic heating he favored an easily burned fuel in solid form rather than gas.

G. F. S.

**Moisture Absorption by Wood Through Varnish.** (*Technical Notes, Forest Products Laboratory*, Madison, Wis., 1919.)—In experiments made by the Forest Products Laboratory, it was found that varnishes do not entirely prevent the transmission of moisture into wood, but merely retard it, and that apparently there is no difference in moisture absorption through the coating due to the species of wood used.

The panels used in the experiment were of yellow birch, basswood, red gum, African mahogany, white ash, white pine, Sitka spruce, southern yellow pine, bald cypress, incense cedar, white oak, western yellow pine, Port Orford cedar, and sugar pine.

Three coats of high-grade spar varnish were applied to four panels of each species. Two panels of each species were brush-coated and two were dipped by a special dipping machine designed to secure an even coating. The panels were allowed to dry seventy-two hours between coats and ten days after the final coat before they were given the moisture-resistance test.

The moisture-resistance test consisted in exposing the panels for seventeen days to a humidity of 95–100 per cent., or in an atmosphere practically saturated with moisture.

At the end of this test, it was found that all the brush-coated panels had absorbed between 5 and 6.5 grammes of moisture per square foot of surface, and the dipped panels between 4 and 5 grammes. Such variations in amount of absorption as appeared could easily have been due to inequalities in the application of the varnish. It was quite noticeable that the dipping process produced a more moisture-resistant coating than brushing.

**The Dye-Stuff Problem.**—In a bulletin (*Tariff Information Series* No. 11) just issued by the United States Government, a large amount of interesting information is given concerning the development and present condition of the dye-stuff supply in this country. It is well known that for many years German dye-stuffs have been in control of the markets of the world, and that dyes of all types have been furnished at low prices and in abundance. Dye manufacturing was carried out in some other countries, even to a limited extent in the United States, but the procedures were largely merely "assembling," that is, bringing together the less complex coal-tar derivatives, commonly called "intermediates," these being in large part imported. A very

interesting and highly important feature of the synthetic dye industry has been the artificial production of certain important natural colors, especially alizarin and indigo. The former was originally obtained only from the madder plant, but its chemical composition and relationships were worked out by German chemists many years ago, and the artificial substance rendered the cultivation of the plant unprofitable. The indigo problem was attacked vigorously, and after a very long and ingenious investigation, was finally solved so that the natural product was driven practically out of the market. Indigo is a typical "vat" dye, that is, the color as it exists in the free state or on the cloth is insoluble in water, but by reduction it becomes colorless and soluble and can then be easily impregnated into the fabric, which by subsequent exposure to air, allows oxidation with the production of the insoluble color. The importance of this particular color is shown by the statistics given in the pamphlet under review. For instance, in 1914 the total importations of indigo (natural and artificial, but presumably almost entirely the latter) were 8,125,211 pounds, of which almost 7,500,000 pounds came from Germany. The total cost was $1,093,266, which is about 12.5 cents a pound. In 1916, 1917 and 1918 no importations from Germany are noted, but it is possible that some of the indigo credited to neutral countries really came from German factories. In 1916, during which the United States was still neutral, about one and one-third million pounds came from England, and over three and one-third million from China. It is probable that much of this from both countries was natural indigo, for the cutting out of the German product enabled the British-India growers to resume cultivation of the plant at considerable profit. The burden imposed by these abnormal conditions is shown by the fact that the indigo imported into the United States in 1916 (nearly 6,600,000 pounds) cost over $8,200,000, about ten times the pound price of the pre-war years.

A special agent has just been sent to Germany to arrange for importation of this and other vat-dyes, which are so much needed by the textile interests of the country. The production of artificial indigo is not a very difficult or complicated process, and in 1917 it was undertaken by an American firm with the result that nearly three hundred thousand pounds were produced that year. In 1918 three firms were engaged in the work and the total product was over three million pounds. It is stated in the report that at present the productive capacity is equal to the total importation for the fiscal year ending June 30, 1914. There is, however, no such record of achievement in the other dyes of the indigo class. Alizarin also, and two alizarin derivatives were made, but in amounts much below the normal demand.

It is gratifying to learn that such progress has been made in the manufacture of certain important synthetic medicinal substances that dependence on Germany is at an end.

Interesting information as to the effect of the synthetic indigo on the production of the natural color is given in a paper by Professor Henry E. Armstrong at a meeting of one of the sections of the Royal Society of Arts (*Jour. Roy. Soc. Arts,* vol. lxvii, p. 446, 1919). When synthetic indigo was first put on the market by the Germans (1897), the area occupied by the indigo culture was 1,688,042 acres. Up to that time the industry had been very prosperous, but the synthetic product at once began to compete, and when the war broke out in 1914 the acreage had fallen to 150,000, about one-tenth the original. The war, of course, by cutting off the opportunities of German competition, gave a chance for advancement of the cultivation of the plant, and by 1917 the acreage had increased to three and one-half times that of the preceding five years. The greatest increase was in Madras, but the encouragement has fallen off materially with the cessation of hostilities, and the production of the natural color is diminishing. In view of what the Americans have accomplished it is likely that the natural product will soon cease to be an important factor in the dye-stuff market. H. L.

**An Extension of Applied Chemistry.** (*Amer. Chem. Soc. News Service.*)—Department stores and mail order houses are now installing chemical laboratories as part of their organization and are retaining chemists by the year.

One large dry goods firm in a city of the Northwest has a complete laboratory in full view of customers in which tests of all kinds of merchandise are conducted. The exact kind of dye in fabrics, the fibres which they contain, whether cotton or wool or silk, or mixtures of various threads, can thus be determined to the satisfaction of both merchant and consumer.

By having the chemist continually checking up on quality of products, large houses which sell merchandise by parcel post over wide areas can describe exactly everything enumerated in their catalogues. Thus they do not guarantee articles until they have had them thoroughly examined. As customers are so scattered over the country, accurate descriptions of merchandise prevent misunderstandings. The cutting down of unnecessary correspondence is one of the economics which has resulted from taking in a chemical partner.

Much as does big business make use of chemistry at the present time, it was only about a quarter of a century ago that it even sensed the relation of research to success in manufacturing and commerce.

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## SOAP BUBBLES OF LONG DURATION.*

BY

SIR JAMES DEWAR, LL.D., D.Sc., F.R.S.

Fullerian Professor of Chemistry, Royal Institution, Honorary Member of the Institute, Franklin Medalist, 1919.

An investigation of the properties of soap bubbles is the logical outcome of the experiments on flat liquid films described in the 1916 Friday Evening Discourse. Some fifty years ago Joseph Plateau—Professor of Physics at Ghent—began a series of investigations on Surface Tension Phenomena, and for nearly forty years carried out a number of wonderful investigations, although practically blind, owing to an accident which occurred while examining the action of intense light on the retina in the early part of his career. It is due to the fascinating character of his pioneer work on soap bubbles that the study has been continued. Since the work of Plateau, great advances have been made in the experimental study of Surface Tension Phenomena by Dupré, Mensbrugghe, Reinold and Rücker, Michelson and his collaborators. The theoretical advancement which science owes to Willard Gibbs dominates all modern research on capillary phenomena.

The flat films described last year were developed in an exhausted atmosphere of nearly pure water vapor; while soap

* Communicated by Sir James Dewar. Lecture delivered before the Royal Institution and later to appear in its Proceedings.

[Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the Journal.]

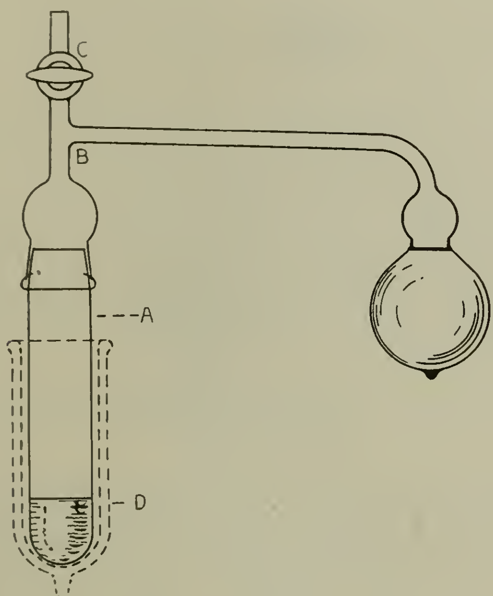
bubbles are blown up with air in air. Experiments extending over a year have proved that in order to keep soap bubbles for any length of time the air must be free from deteriorating gases and suspended solid matters. The presence of living organisms and their spores amongst the finely divided organic and inorganic particles in the atmosphere was discovered by Pasteur. He purified the air by passing it through a red-hot platinum tube containing platinum gauze, afterwards removing the total carbonic acid. Later Tyndall used a concentrated beam of light to demonstrate the presence of floating impurities in the air, as a test of "optical emptiness." Tyndall passed a parallel beam from an arc lamp through a large plano-convex lens, which condenses the light into a cone, at the apex of which the intensity of the illumination causes the floating matter in the air to be easily recognized. If a Bunsen or hydrogen flame is placed below the focus, the reflected light gradually disappears as the floating material, being largely organic, is burnt and passes into the gaseous state. Another method used by Tyndall to obtain a dust-free space was by smearing the interior surface of a glass box with glycerine, closing and allowing it to stand for a few days, when the dust settled, adhering to the glycerine. On applying the light beam test, the box was found to be what Tyndall termed "optically empty." Aitken has devised an apparatus for counting the particles in the air, suggested by experiments on cloud condensation due to the cold produced by sudden expansion of air saturated with water vapor. Very briefly his method is to make these solid particles the nuclei of small raindrops, which can then be counted. Ordinary London air contains about 100,000 suspended particles, organic and inorganic, per cubic centimetre. The particles get coated with all kinds of adherent organic matter which, coming in contact with the bubble, affects its surface tension locally, thereby inducing instability.

When bubbles blown with pure air were formed in vessels closed to prevent communication with the outside air, it was soon recognized that, when the interior of the vessel had become free from suspended matter by long standing and deposition on the walls the surface of which was coated with glycerine soap solution, the bubbles lasted much longer.

The methods of purification employed for the purpose of obtaining long-lived soap bubbles were (1) simple displacement by

purified air; (2) deposition of the solid material by electrical discharge in the space to be utilized. To demonstrate the two methods, domed glass shades about 2 feet high were used, each with a black wood base, in which was a circular glass window. A concentrated beam of light from an arc lamp was reflected up through the window, thus strongly illuminating the solid impurities in the air-space enclosed by the shade. Highly compressed air from an ordinary steel bottle, purified by passing it

FIG. 1.




through three small glass towers containing, respectively, soda, lime, and cotton-wool damped with glycerine, was introduced in the bottom of the shade through holes in a circle of lead pipe secured on its wooden base. In about a minute the beam disappeared as the impure air was swept out through a small hole in the top of the shade. To show the electrical method of purification a similarly fitted shade had an insulated steel point hung within it from the centre of the dome. This was connected to one pole of a Wimshurst machine, while the other was earthed along with the lead pipe described above. Within two minutes of starting the point-discharge the illuminated cloud had practically

disappeared. When this treatment was applied to a vessel containing soap solution, a heavy mist of large floating water particles first appeared, of some persistence.

### BUBBLES FROM THE EVAPORATION OF LIQUID AIR.

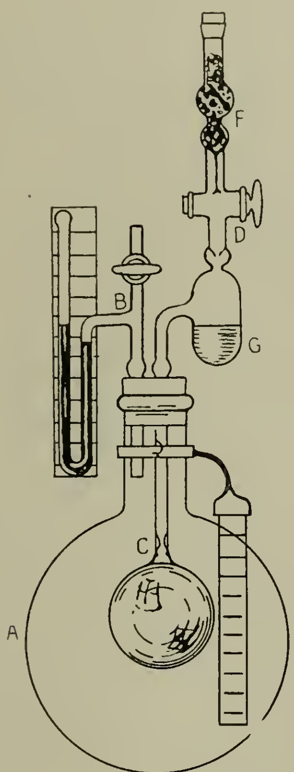
The evaporation of liquid air readily affords a supply of pure mixed oxygen and nitrogen. Apparatus for this purpose is shown in Fig. 1. The liquid air is contained in a tube, *A*, which is fitted by a ground cap to the delivery tube, *B*, and placed in a vacuum vessel, *D*, to control heat influx. At *B* one branch tube leads to the thistle-shaped funnel from which the bubble is to be suspended, while another branch leads to the stop-cock, *C*, by means of which the admission of air into the bubble can be regulated. The cavity above the ground cap, and the horizontal tube leading to the bubble are packed with copper-wire gauze in order to warm the air evaporated. The soap solution is supplied to the mouth of the thistle-shaped funnel in the usual way: or otherwise, by having a constriction in the tube above the thistle-shaped funnel, together with a stoppered dropping funnel. It is thus possible to fill the constriction with soap solution, and develop bubbles singly or in succesion, as desired.

### APPARATUS FOR THE PRODUCTION OF BUBBLES UNDER VARIOUS PRESSURES.

The apparatus (Fig. 2) is a spherical glass flask, *A*, of 2½ litres capacity, fitted with an india-rubber cork which has been previously cut and steamed in order to remove volatile organic matter. The tube, *B*, leads from the vessel, *A*, to a mercury U-tube manometer, and to the stop-cock to which the air-pump is attached; while another tube carries at its lower end the constriction, *C*, and the funnel on which the bubble is to be formed, and at the upper end the small reservoir, *G*, of soap solution. Air passing through the purifying bulbs, *F*, is admitted by the regulating stop-cock, *D*, through the reservoir, *G*, to the funnel-mouth, *C*. A capillary tube between *D* and *G* assists in the control of air when the pressure in *A* is very small. By slightly tilting a few drops of the solution in *G* down the tube to *C*, bubbles are easily blown within the flask, *A*, even at a pressure less than 1 mm. Hg. At this pressure the contraction of the bubble proceeded visibly, and was accelerated as the diameter was reduced.

In Fig. 3 various forms of bubble-support tubes are shown, convenient for different purposes: (*a*) permits the insertion of a long fine tube or rod into the bubble; (*b*) allows the apparatus to be inverted, without loss of soap solution, so as to have the bubble supported from below; (*c*) permits the formation of

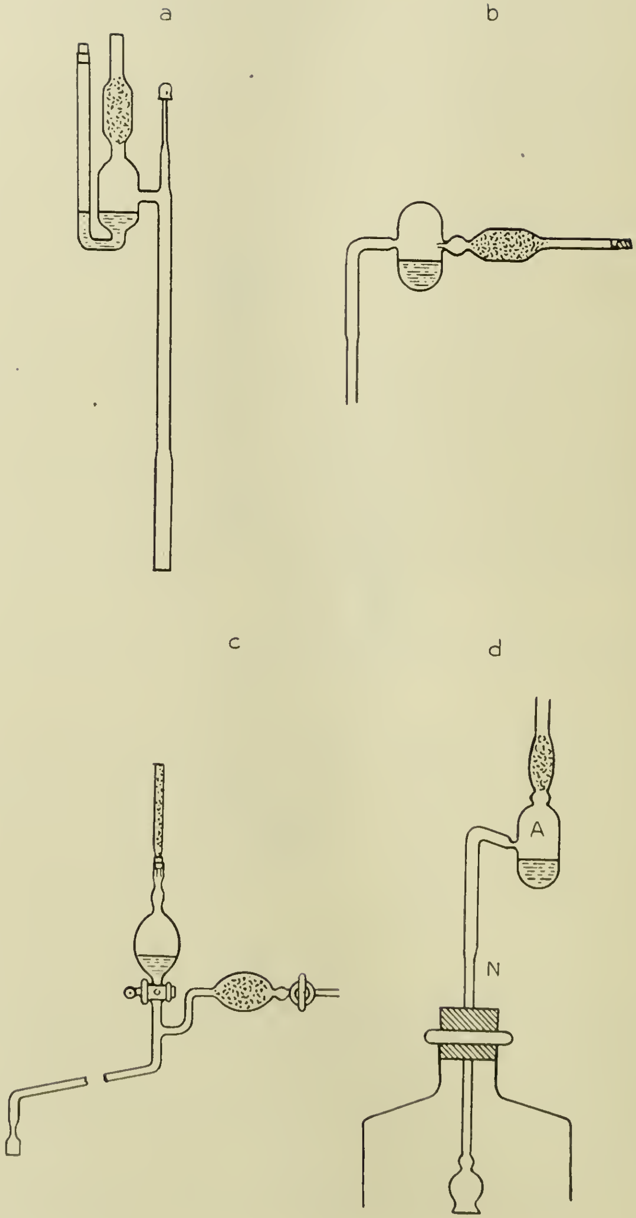
FIG. 2.




bubbles in otherwise inaccessible places (this form has a dropping funnel and stop-cock attachment to the reservoir); (*d*) is useful for forming a succession of bubbles (by a series of slight regulated jerks of the reservoir, a series of films form in its exit-tube, which pass down to the thistle-shaped funnel, and there produce a chain of bubbles).

An ordinary tubulated aspirator, of about 12 litres capacity, is

FIG. 3.



very convenient for the study of bubbles up to nearly 20 cm. in diameter. For careful measurements a plane-sided vessel is necessary to prevent optical distortion. For this purpose a metal-framed plate-glass box, 1 foot length of side, was used. The sheet of glass forming the top was nearly 6 mm. thick; it was pierced with three or four holes from ½ cm. to 3 cm. diameter, besides the central hole, 3 cm. in diameter, for supporting the blowing tube. These extra holes allow the admission of flexible glass supporting rings, or draining points, where necessary. Thus, by means of the dropper (Fig. 3*a*), a fine glass thread or wire can be passed down through the bubble, so that the drop is removed and the distortion observed. Similarly, through one of the openings in the lid of the cubical glass chamber, a thin glass rod with an up-turned end, approaching the bubble from below, can be employed to drain off any excess of liquid, and thereafter to determine the changes effected in the vertical and horizontal diameters.

### DISTORTION OF BUBBLES, HANGING OR SUPPORTED.

The following instances show the amount of distortion or ellipticity, present in hanging bubbles, under different conditions:

A bubble, 19.1 cm. vertical diameter, 17.8 cm. horizontal diameter (ellipticity 7 per cent.), when freshly blown from solution of 5 per cent. potassium oleate, 50 per cent. glycerine, was only feebly colored, and therefore fairly thick. On the fourth day its vertical diameter was 18.1 cm., and on the fifth day 17.7 cm., being then sufficiently thinned to be well colored.

A bubble of 5 per cent. ammonium oleate in 50 per cent. glycerine, measuring 17.25 cm. vertically and 16.2 cm. horizontally (ellipticity 6 per cent.) was at first only feebly colored in the lower one-fourth. By the third day the vertical diameter was reduced to 16.6 cm. from the reduction of mass, shown by an intensification of the coloring. A bubble of this composition exposed to water vapor, by running water into the containing vessel, will condense and absorb the water vapor and become thickened again for a time. Such a bubble of 30 cm. vertical diameter was dragged down by the water it absorbed in one day to 31.8 cm., an elongation of 6 per cent.

A bubble, 11.2 cm. diameter, with the upper half black and lower half colored, was reduced to 10 cm. diameter, when entirely

black, by drainage—*i.e.,* a distortion of 12 per cent. vertically was caused by the lower half of a thin black bubble thickening to show color by adding a few drops of soap solution.

If instead of the bubble being supported from above it rests on a suitable light ring support, it will obviously decrease in vertical diameter when it becomes thickened and weighted. This was frequently observed with bubbles of about 40 cm. diameter, resting on a 10 to 12-cm. ring of thin iron wire.

With a water layer in the globe, considerable variations were noted from day to day, *e.g.*—

Thus, a bubble colored green and carmine, very brilliant but fairly thick, 42.6 cm. diameter, thinned to half black and half silvery (next thicker color to black), 43.6 cm. diameter.

Another bubble colored amber to purple, near lower limit of thickness to show color, 22.7 cm. diameter, thinned to all black (thinnest possible), 23 cm. diameter.

A colored bubble 43.3 cm. diameter, thickened in 15 minutes by condensation to 42.7 cm. diameter.

Bubbles of such a size flattened down on their supporting rings as they became thicker and heavier, and could be seen hanging over the ring-support from this cause.

A bubble 39 cm. diameter, hanging from a 4-cm. glass funnel support, thinned to over 70 per cent. black on its second day, and increased until its 63rd day, when it burst, 80 per cent. black. On five occasions a slowly accumulated drop was observed to fall off—namely, on the 6th, 10th, 20th, 27th, and 52nd days respectively. The alterations in diameter which thereupon resulted were as follows:

| | | | | | |
|---|---|---|---|---|---|
| With drop ......... | 39.0 | 39.05 | 38.95 | 38.45 | 37.80 cm. |
| Drop fallen ........ | 38.5 | 38.55 | 38.40 | 37.90 | 36.95 cm. |
| Alteration .......... | 0.5 | 0.50 | 0.55 | 0.55 | 0.85 cm. |

This bubble was blown from a solution containing 10 per cent. ammonium oleate and 50 per cent. of glycerine.

A bubble of similar size, but resting on a ring, varied in vertical diameter as follows:

42.6 cm. when fairly thick, at first.
43.5 cm. 15th day.
43.0 cm. 16th day, orange to amber.

43.3 cm. 17th day, 80 per cent. black.
43.0 cm. 18th day, four-fifths deep orange, one-fifth purple;

thus rising higher on its ring-support as it became thinner.

The maximum amount of distortion by loading which a bubble of this size can maintain was observed in one case by expanding the bubble until the distortion at the rim-support, 4 cm. in diameter, showed that it was nearly being dragged off. The dimensions were then 45.4 cm. vertically and 40.1 cm. horizontally (ellipticity 11.7 per cent.). The diminution in vertical diameter by the release of a single drop was 2.1 cm., showing the near approach to instability. After fourteen days the drainage reduced the loading of the bubble so that the vertical diameter became substantially constant, as shown by the following records:

| | | | |
|---|---|---|---|
| Day ........................ | 7th | 14th | 21st. |
| Diameter .................... | 44.3 | 41.6 | 41.8 |

After this date the bubble remained colored in the lower three-fourths of its area. In this condition the distortion caused by one drop was approximately 1 cm. The persistence of the colored stage could be maintained by a very minute continuous leak of solution from the reservoir into the supporting nozzle. When the soap solution supply was stopped, the development continued to the black state. When completely black the whole mass, in a bubble 40 cm. in diameter, is of the order of 50 mgms., so that the bubbles are very susceptible to disturbance from shock to the containing vessel. Local or sudden changes of temperature must also be avoided, as strong convection currents are thereby set up. Such currents become evident by innumerable silvery discs (see p. 738) streaming continuously in many directions over the black film. The thicker silvery discs floating for a time on a thinner black film represent excess of liquid drawn in either from the drop below or the ring of liquid, at the contact of the bubble with the supporting nozzle. By the use of closed vessels the nozzle is kept constantly moist, and this is probably a factor in the preservation of black bubbles.

DURATION OF LIFE OF VARIOUS BUBBLES.

The records of a large number of bubbles, up to 46 cm. in diameter, have been preserved. Some extracts are condensed in the following summary:

TABLE I.

*Lives of Various Bubbles.**

| | |
|---|---|
| Three, 16–18 cm., 50 per cent. glycerine, 5 per cent. soap, water in vessel; temperature 10°–20° C. | 28–42 days. |
| One, 14 cm., 50 per cent. glycerine, 14 per cent soap, water in vessel; half black at end; temperature 4°–11° C. | 98 days. |
| One, 20 cm., 50 per cent. glycerine, 5 per cent. soap; temperature 9°–11° C.; over 60 per cent. black at end | 95 days. |
| One, 12 cm., 30 per cent. glycerine, 3 per cent. soap; temperature 10°–20° C. | 30 days. |
| Black horizontal film, 20 cm. diam., 50 per cent. glycerine, 5 per cent. soap; temperature 4°–20° C. | over 1 year. |

* NOTE: A hanging bubble blown and kept in air saturated with water vapor, of a capacity of 4.5 litres, took 322 days to completely collapse from air transfusion.

TABLE II.

*Life of Successive Bubbles. 40 cm. Bubbles on Ring.*

| 1st 200-litre vessel | | 2nd 200-litre vessel |
|---|---|---|
| 1st bubble (vessel dry) | 3 days | 1st, 5 days |
| 2d bubble (water in vessel) | 7 days | 2d, few hours (ring rusty) |
| 3d bubble (water in vessel) | 10 days | 3d, 3 days |
| 4th bubble (water in vessel) | 24 days | 4th, 18 days |
| 5th bubble (water in vessel, vibration) | 19 days | 5th, 11 days (hot weather, etc.) |
| 6th bubble (water in vessel) | 55 days | 6th, 63 days (hanging on 4 cm. support) |
| 7th bubble (water in vessel, out in yard, frosty at end) | 31 days | 7th, 42 days (globe became contaminated) |

The first item of Table I includes the first bubble (50 per cent. glycerine, 5 per cent. ammonium oleate), which kept its color instead of developing to blackness. This was caused by moisture left after cleaning the 5-litre bottle in which it was blown; no more moisture than enough to give a bedewed appearance was left, but this distilled to different parts of the vessel, as the local temperature altered, and resulted in a movement of water vapor sufficient to keep the absorbent bubble thick enough to show colors.

Sharply marked zones of different colors are a feature of such bubbles. For this an undisturbed atmosphere is necessary; otherwise convection currents in the bubble will, by continual mixing, prevent the quiet development of separate color zones. The temperature alterations must, therefore, be small. From the records of one bubble the following appearances were noted:

On the 15th day. 20 cm. in diameter: sharp boundary line at "60° N. Lat." between steel-blue above and greenish-yellow below: similar boundary between blue-green and blue-purple at "50° S. Lat." Large drop on bubble.

On the 18th day. Diameter, 19.4 cm.: three sharp line boundaries: green to purple at "30° N.": dark green to light green at "70° S.": light green to thin magenta at "80° S.": intense green disc at lowest part. Drop fallen off.

On the 24th day. Main area of bubble fairly uniform red-purple: boundary at "75° N." to pale green above, and to deep green below at "60° S." Graded Newton's rings of mauve and green below this.

The life of the bubble shown in the second item of Table I was double that of those in the first item, namely, 98 days instead of about 40 days. The solution used had 10 per cent. of ammonium oleate instead of 5 per cent. as before. This factor, however, had less influence than the generally lower temperature of under 11° C. instead of up to 20° C. as before. Between the 75th and 95th days there was a contraction from 11.4 cm. diameter to 10.4 cm., while still remaining colored. By the 95th day the bubble had become too dilute to maintain any color, and accordingly developed to the thinnest or "black" stage in the upper half. On the night of the 98th day the temperature of the Laboratory fell to near freezing point, and the bubble did not survive this change.

The next item refers to a bubble of 5 per cent. potassium oleate in 50 per cent. glycerine. The 12-litre aspirator in which it was blown was well dried, and, further, was placed in a vault where only slow and small temperature variation occurs. In three months the variation was from 9° C. to 11° C. This solution was chosen because of its property of giving extremely slow development to the "black" stage. The result was that in 95 days the zone of black had only extended down to "25° S. Lat.," the remainder being so thick as only to be feebly colored with faint pink-and-green rings, probably up to a hundred times the thickness of the black supporting zone above. The final collapse may have been associated with this condition; moreover, the potash soap is very sensitive to slight alkalinity of the glass—no other disturbing cause was observed.

Table II shows the lives of two sets of large bubbles under

similar conditions, in two vessels of 200-litre capacity (Fig 4). These vessels were cylindrical glass globes, used in the Laboratory twenty-five years ago in the production of liquid ethylene. They had short necks, 14 cm. diameter, which were fitted with good, cleansed india-rubber corks to carry the blowing tubes, vent tubes, etc. An oxidized steel wire ring was used to support the

FIG. 4.

majority of the bubbles. These rings were about 12 cm. diameter, and were raised, by three supports of the same oxidized wire, to about 25 cm. above the bottom of the globe. For bubbles so supported the blowing tube was less than 1 cm. diameter; it had a constriction of about 1 mm. bore, a few centimetres above the lower end. A few drops of liquid from the reservoir above were decanted down to fill the constriction for the purpose of starting the bubble. The reservoir is shut off by a stop-cock from the blowing tube, as it is not advantageous for the soap solution to be exposed to the current of air used in expanding the bubble:

a side tube is sealed in for the air inlet. The blowing tube is mounted, so that it can slide up and down while remaining air-tight. A few small bubbles are first blown and run round the supporting ring to wet it. A bubble is then blown to about 4 cm. greater diameter than the ring, while resting on one side of it. This is done by holding the end of the blowing tube sufficiently out of the centre, and steadily raising it until the bubble is about 15 cm. diameter, when it is allowed to come into full contact with the whole ring, and the expansion is continued until the requisite diameter of about 40 cm. is reached. Meanwhile, the blowing tube is continually raised through its sliding support tube in the india-rubber cork, and finally withdrawn by a to-and-fro spiral movement upwards. In one case when the bubble became free from the tube, a complex up-and-down oscillation took place in a period of about two seconds, and with an initial amplitude approaching 3 cm. at the upper periphery. By leaving the blowing tube in the bubble the advantage of an added steady support is secured: this is unsatisfactory when measures of contraction are being made, but it certainly helps to prevent undue disturbance, especially in the early stages, when the bubble is liable to be thick and somewhat top-heavy on the 10 cm. ring.

It can be seen fromTable II that there is a general increase in length of life of the successive bubbles in both the first and second vessels. The last items, in both cases, show a shorter life; this, however, was due in one case to the vessel being in the open air in winter, whereby its temperature at the end went below freezing point; and in the second case, to the globe becoming contaminated, from the displacement of a badly fitting tube. The irregularity between the fourth and fifth items was explained by the hot weather (temperature over 20° C.).

The maintenance of color in such large bubbles was not easy. For this purpose a good circulation of water vapor in the vessel seems desirable, as the mere presence of a litre or two of water in it was not entirely effective. A wet cloth placed on the upper part of the vessel (seen in Fig. 4) by its own evaporation maintained a slightly cooler area, thus promoting the condensation there of drops of water. A flow of water vapor up through the vessel was thus obtained, which being partly absorbed by the glycerine in the bubble did for a time maintain, and even increase, its thickness and color. In the later stages also, when the bubble material

has thus become altered in the relative proportions of its constituents, vaporization from the bubble may take place, and then the opposite effect is observed; distillation causing the thickness to decrease, so that two or three colors are passed through in as many hours. A few degrees rise of room temperature causes the same change, especially in diluted bubbles. The lowering of the temperature will then reverse the effect and the bubble is seen to thicken. The ordinary variations from night to day are sufficient to cause many such repetitions in the same bubble. Thus, when it was thought to increase the proportion of water vapor by warming the water in the vessel, and thereby increasing the thickness by a greater absorption, the rise of temperature counteracted any increased absorption; and once more the bubble became thinner. The removal of the wet cloth allows the condensed water to distil off more vapor, which is often sufficient to thicken the bubble. This is best seen when a good condensed deposit is accumulated before blowing the bubble, as was done in one case (see fifth bubble, first vessel) by the application of bags of ice. The bubble, which was then blown, remained almost entirely colored throughout its life. A small zone of black came and went, and the thickness was reduced once or twice by a damp cloth. The weather was rather warm at first, but became more temperate (the time was August). Finally, the bubble was very much thickened, and probably burst from this cause; for as the bubble became thick, it overhung the ring unsymmetrically, and most probably became lopsided enough to swing round and touch the vessel. The supporting ring was seen to be slightly out of the horizontal, and in vibration due to the working machinery in the room below.

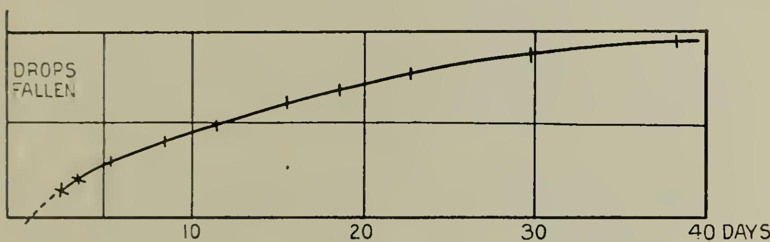
The fourth bubble in the second vessel: during the first week untouched; maintained green and pink color; thick and overhanging the ring; then frequently treated by damp cloth above, thinned while cloth was on and thickened when cloth was removed; at third operation, bubble half black; next time, the water below was warmed by the arc lamp beam: result, 85 per cent. black obtained.

The fifth bubble in the second vessel lasted eleven days only; short life in the hot weather; disturbed at the end by damp cloth, also by vibration; thinned to silver and black; first three days thickened rapidly by absorption from the deposit of water; im-

mediately after being blown sagged over ring; then steadily thinned through several beautiful grades, until on the fifth day at 19½° C. it was amber and purple, with silver above. Damp cloth then put on; the silver extended all over, followed by a fairly uniform development of black. Two grades of black were noted—the deepest black being only a zone of a few centimetres at the top. The top of the bubble was approximately 1 cm. higher when black than when thick and heavy.

The sixth bubble in the first vessel went quickly black in two days (possibly from an unusual excess of ammonia in the soap solution). and remained so until the end of the first week. It then thickened to various colors for four weeks, and once again went

FIG. 5.




Absorption of water vapor by a 40 cm. bubble. Rate of fall of drops.

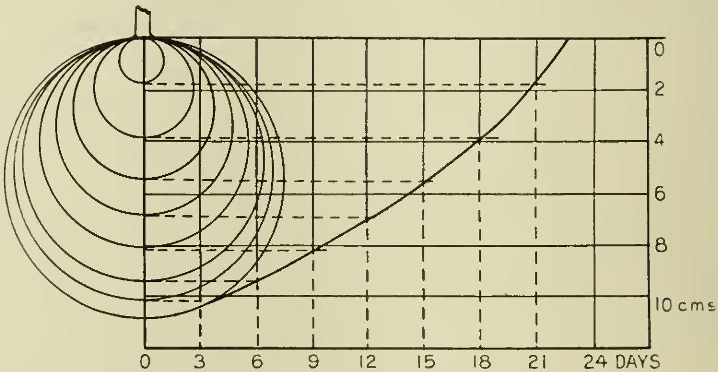
quickly black. This condition remained for three weeks, during which time a steady diminution of diameter was measured. The blowing-tube having been left attached to the bubble, the contraction had by time narrowed down the upper part of the bubble till it became a neck. When this divided, the disturbance was probably more than the very dilute and very thin film could survive, for the next morning it had gone.

The seventh bubble in the second vessel was suspended from a 4-cm. nozzle; it lasted from October 27th to December 9th. The temperature fell from 15° C. at first to below 10° C. after the first week. The bubble burst after a sudden rise of temperature from 6° to over 9°, accompanied by a considerable fluctuating fall in the barometer, when it was found, by the optical test, that the air in the globe had become contaminated. This bubble afforded an opportunity for observing the rate of fall of condensation drops. Excluding the preliminary drainage, the results are shown in the annexed diagram (Fig. 5).

GAS TRANSFERENCE THROUGH BUBBLES AT ATMOSPHERIC PRESSURE.

Long-lived bubbles regularly diminish in diameter, and most rapidly when thinned to "black." The contained air or other gas is at a somewhat higher pressure than the atmosphere in which the bubble stands, and therefore tends to pass out; with the result that there is a continual diminution in size. With black bubbles up to about 15 cm. the change becomes very evident in about a week. Using a cathetometer, the contraction can be observed accurately from day to day. The subjoined diagram (Fig. 6)

FIG. 6.




Black bubble in hydrogen. Decrease in size at 3-day intervals.

shows the contraction, measured every third day, of a black bubble in hydrogen. From an initial diameter of approximately 11 cm., by the twenty-third day it had completely contracted. It will be noticed that the rate of contraction was accelerated as the diameter decreased.

The gradational diminution in diameter of black bubbles made from soap solutions of different compositions, and with diameters up to 46 cm., was periodically measured with the cathetometer.

The rate of gas transference from within the bubble outwards at any time can be obtained directly from the mean daily reduction in diameter at that time, and is readily measured by $dy/dx$, the slope of the tangent drawn at the desired point of the contraction curve. The amount of the gas transference, in cubic centimetres per day through unit area, is then equal to one-half of the daily rate of reduction in diameter, measured in centimetres.

This follows directly from the simple properties of a sphere;

for if $S$ and $V$ be respectively the surface and volume, and $D$ the diameter, then $S=\pi D^2$, and $V=\frac{\pi}{6}D^3$, so that $dV=\frac{\pi}{2}D^2.dD$ $=\frac{1}{2}S.dD$, therefore $dV/S$, the rate of gas transference per unit surface, $=\frac{1}{2}.dD$, which is half $dy/dx$, the daily rate of reduction in diameter shown by the slope of the tangent already referred to.

Some of the results obtained are shown in the following Tables III, IV, V, and VI, in which are given respectively (1) the diameter of the bubble on which the measures were made; (2) the corresponding internal excess pressure, above the exterior air pressure, given in mm. water; and (3) the measured value of $dD/2$, representing, as shown above, the rate of gas transference in cubic centimetres per day passing out through each square centimetre of the bubble when at the diameter given in line (1).

*Gas Transference Through Black Air Bubbles.*

TABLE III.

*Fifty Per Cent. Glycerine, 2½ Per Cent. Soap; Hanging on Glass Tube.*

| | | | |
|---|---|---|---|
| Diameter | 6 | 7 | 8 |
| Internal pressure | 0.30 | 0.26 | 0.23 |
| Gas transference rate | 0.065 | 0.035 | 0.030 |

TABLE IV.

*Twenty-five Per Cent. Glycerine, 4 Per Cent. Alcohol, 5 Per Cent. Soap; Hanging on Glass Tube.*

| | | |
|---|---|---|
| Diameter | 10 | 12 |
| Internal pressure | 0.18 | 0.15 |
| Rate | 0.15 | 0.11 |

TABLE V.

*Two Large Black Bubbles (Thinned by Water Condensation); Hanging on a Glass Tube.*

| | I | II |
|---|---|---|
| Diameter | 38 | 38 |
| Internal pressure | 0.057 | 0.057 |
| Rate | 0.023 | 0.015 |

The corresponding rates calculated for similar bubbles 10 cm. diameter would be: (1) 0.086; (2) 0.58; whereas a bubble subject to water condensation, but still retaining some color, contracted from 11 cm. diameter on its 75th day to 10 cm. diameter on the 95th day, being a diminution of 1 cm. in twenty days, giv-

ing an average daily rate of gas transference per unit of surface equal to 0.025 cm., or about one-third the calculated rate for a black bubble of the same diameter.

Table V may be amplified as follows, to show more completely what is occurring in bubbles of this size:

TABLE VI.

*Gas Transference Through 38 cm. Black Bubbles in Air (Dilute Glycerine-Oleate Solution).*

| Results. | | (I) 5 weeks black* | (II) 2 weeks black† |
|---|---|---|---|
| Diminution in diameter | Daily | 0.045 cm. | 0.03 cm. |
| | Total | 1.58 cm. | 0.41 cm. |
| Diminution in volume | Daily | 0.103 litres | 0.067 litres |
| | Total | 3.60 litres | 0.940 litres |
| Gas transference through each sq. cm. | Daily | 0.023 c.c. | 0.015 c.c. |
| | Total | 0.805 c.c. | 0.205 c.c. |

* No. I, hanging on a glass tube. † No. II, less diluted than No. I, and resting on a steel-wire ring.

In the case of a hanging bubble as large as 38 cm., referred to in Table VI, the total reduction in the diameter amounts only to 1.58 cm. in five weeks. The volume of such a bubble is over 30 litres, and the surface has an area of 5000 square cm., while the total weight is only about half a gram. Being thinned to the "black" stage, it has a maximum thickness of approximately fifteen $\mu\mu$'s; that is to say, one and two-third million such films if superposed would have a total thickness of one inch. The internal excess pressure is of the order of a twentieth of a millimetre of water, or about one fifteen-thousandth part of the pressure of the atmosphere. Nevertheless, the actual volume of air which passed out of the black bubble in five weeks was 3.6 litres, or every minute a layer of air molecules some ten to eleven times the thickness of the wall of a black bubble of 38 cm. diameter passed through it. Hence, the thickness of the layer of air which at ordinary temperature passes through the film in one second is 10/60ths of the thickness of the film, or 2.5 $\mu\mu$'s—in other words, a layer of air as thick as the film would take six seconds to pass through it. Again, the mean free path in air is 100 $\mu\mu$'s, which is nearly seven times the thickness of the film, and therefore some forty times the thickness of the layer of air passing through the film in one second. Theoretically the internal pressure in a black bubble of less than about 1 cm. diameter would be sufficient to cause the transference of a layer of gas of a thickness equal to the length of

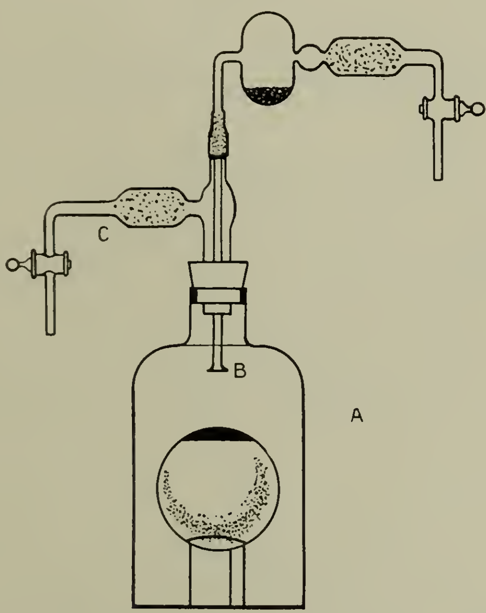
the mean free path. The rate of transference in bubble II is only about three-quarters of that in bubble I.

A black air bubble about 42 cm. diameter, supported by nozzle above and a small fixed horizontal glass ring below; thus keeping its vertical diameter constant; altered to an ovoid shape. The lessened internal pressure caused the rate of air transference to fall to about one quarter of that in bubble I.

*Gas Transference Through Black Bubbles in Hydrogen.*

A few hydrogen bubbles blown in hydrogen were also observed. A suitable vessel for these bubbles is shown in Fig. 7.

FIG. 7.




An oxidized iron-wire ring is seen supporting a bubble, not yet completely black, within the flat-bottomed vessel, *A* (about 3 litres capacity). The filling of the vessel *A* with hydrogen is attended with considerable difficulty, and requires great care in order to obtain "optical emptiness" in the vessel. The nozzle *B* should be pushed down nearly to the bottom, while the vessel *A* is being filled with hydrogen by the tube *C* (used later as an outlet when expanding the bubble). No Tyndall cone will be

visible if the vessel is properly filled. The bubble is then blown on $B$ in the usual way, and expanded and let down to rest on the wetted ring already prepared for it; or it may be left suspended from the nozzle. Both inlet and outlet tubes are protected by glycerined cotton-wool filters.

The contractions observed in hydrogen bulbs were generally more rapid than those of similar-sized air-bubbles, as shown in Tables VII, VIII, IX, where the units are the same as in the last tables.

TABLE VII.

*Fifty Per Cent. Glycerine, 5 Per Cent. Soap.*

| | Hanging from glass nozzle. | | | | Standing on iron-wire ring. | | |
|---|---|---|---|---|---|---|---|
| Diameter | 4 | 6 | 8 | 10 | 6 | 8 | 10 |
| Internal pressure | 0.45 | 0.30 | 0.23 | 0.18 | 0.30 | 0.23 | 0.18 |
| Rate of gas transference | 0.22 | 0.14 | 0.10 | 0.053 | 0.253 | 0.218 | 0.190 |

TABLE VIII.

*Thirty-three Per Cent. Glycerine, 3 Per Cent. Soap; Hanging from Glass Nozzles*

| | | | | |
|---|---|---|---|---|
| Diameter | 4 | 6 | 8 | 10 |
| Internal pressure | 0.45 | 0.30 | 0.23 | 0.18 |
| Rate of gas transference | 0.31 | 0.25 | 0.20 | 0.17 |

TABLE IX.

*Approximately 1 Per Cent. Glycerine-Soap; Pale Golden Color; Hanging from Glass Nozzles.*

| | | | |
|---|---|---|---|
| Diameter | 4 | 6 | 8 |
| Internal pressure | 0.55 | 0.36 | 0.28 |
| Rate of gas transference | 0.285 | 0.103 | 0.050 |

The internal pressure was not determined for every bubble; the values given above were deduced from results obtained with typical bubbles connected to an alcohol nearly horizontal displacement manometer. The instrument gave with 1 mm. of water pressure a displacement of the order of 100 mm. of the alcohol column.

A study of these results shows at once that there are obscure factors in some cases, causing notable divergencies, even when the conditions are not greatly altered. Other experiments have shown that small differences in composition have in many cases a large effect on the behavior of these thin films. Table IV (air bubbles)

shows that 4 per cent. of alcohol added to the soap solution increases the rate of gas transference through an air bubble.

The constancy in thickness of the "black stage" is undoubtedly subject to variation in different solutions. Johonnott, using a large number of small black films in a Michelson interferometer, found that there were at least two values for the thickness of the black film he measured, and that the additions of either glycerine or potassium nitrate tended to give the thicker of the two* In last year's discourse a description of five distinct grades of black was given, obtained with soap solution containing over 30 per cent. of glycerine. The film covered a thin glass frame in an exhausted glass vessel. These grades were seen to be unstable, coalescing to the deepest or thinnest black when a portion of soap solution was brought in contact with the lower part of the glass frame. It is possible that a few per cent. of alcohol, with its low viscosity and surface tension, might result in a still thinner black stage.

### GAS TRANSFERENCE THROUGH BUBBLES AT PRESSURES OTHER THAN ATMOSPHERIC.

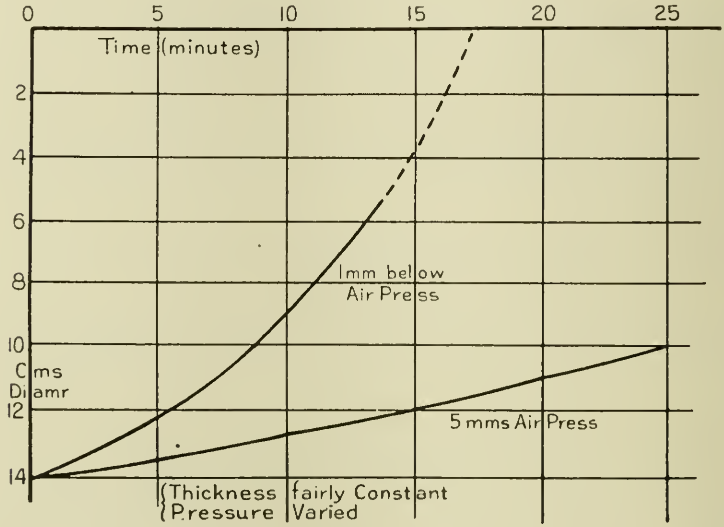
A bubble of about 10 cm. diameter, shown in an exhausted flask (Fig. 2), in which the air pressure had been reduced to the order of a fraction of a mm., was seen to contract visibly from the rapid percolation of the air from within outwards. Under such conditions the small internal excess pressure of about 0.2 mm. water, necessary to maintain a 10 cm. bubble, is a very large proportion, say about 10 per cent., of the total air pressure in the flask. There is, therefore, a proportionately small resistance to its percolation through a film sufficiently thin. As the air pressure in the vessel is increased, the time for complete contraction becomes greater, because the internal excess pressure is a relatively smaller proportion of the total opposing pressure; thus when the containing vessel is at atmospheric pressure, the 10 cm. bubble is distended by only $\frac{1}{5000}$th of this total pressure. There is, therefore, a proportionately small force urging the contained air to pass out compared with that where the vessel was under a pressure of only a fraction of a mm. The result is naturally that the complete

* "Thickness of the Black Spot in Liquid Films." By Edwin S. Johonnott, Jr., Ryerston Physical Laboratory, University of Chicago, *Phil. Mag.*, xlvii. p. 501.

contraction takes weeks instead of minutes. In the same way if a bubble be formed in a strong glass vessel charged to, say, 10 atmospheres, then even after six months, during the major part of the time being black, no sensible diminution in diameter was detected.

The measures of contraction at very low pressures were hindered by the difficulty in securing uniformity of thickness in the film. The black bubbles when obtained are extremely fugitive, as they contract so quickly. Then also the ammonium oleate solu-

FIG. 8.




Bubbles of ammonium oleate, 3 per cent. in 30 per cent. glycerine. Thinned to first green.

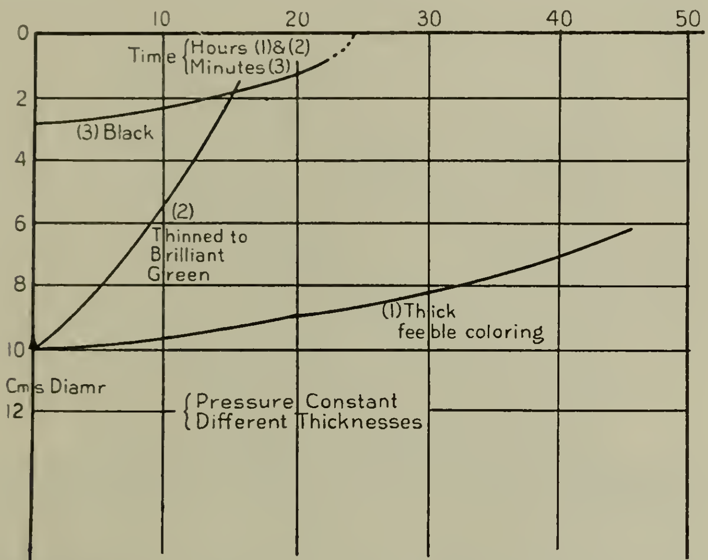
tions, which are so well adapted for obtaining black bubbles, do not remain of the same composition under low air pressures, due to the removal of the volatile easily dissociated ammonia.

The results of some of the attempts with ammonium oleates are given in Fig. 8, showing the contraction of pressures of 1 mm. and 5 mm. Hg. respectively, with approximately the same bubble thickness. The curves in Fig. 9 show the relative rates of contraction with potassium oleate at three different thicknesses of bubble, all at the same pressure of just over 1 mm. Hg.

The first of these two diagrams shows that at less than 1 mm. pressure of air in the vessel, a 14-cm. bubble composed of 3 per cent. ammonium oleate in 30 per cent. glycerine, of intense green

coloration, contracts completely in about 17 minutes; whereas if the air pressure be raised to 5 mm., the contraction of a similar bubble has only gone from 14 cm. to 11½ cm. in the same time, and to 10 cm. in 25 minutes. The second diagram shows that a bubble 10 cm. in diameter, composed of 5 per cent. potassium oleate, 50 per cent. glycerine, and almost too thick to show color, takes 47 hours to contract to 6 cm.; but when a bubble of similar size and composition is thinned to intense green, the same amount

FIG. 9.




Bubbles of potassium oleate, 5 per cent. in 50 per cent. glycerine. Air pressure over 1 mm. hg.

of contraction occurs in 9 hours; when further, the black stage is secured, the time for complete collapse from 3 cm. diameter is only 25 minutes. The green bubble, from its graph, would have taken from 2 to 3 hours for the same contraction. Such preliminary results may serve at least to point the way to a more complete inquiry.

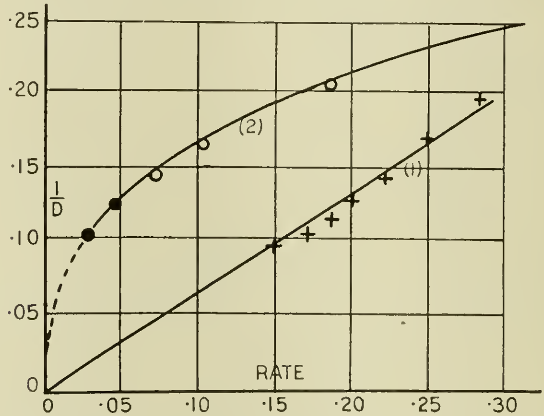
### EFFECT ON THE GAS TRANSFERENCE RATE OF THE COMPOSITION OF THE SOAP SOLUTION.

The internal excess pressure, $P$, in a bubble of constant composition, and therefore of constant surface tension, $T$, enclosed in

a vessel sealed off from the atmosphere, varies inversely as the diameter, $D$, according to the law $P=4T/D$.

Hence, if the rate of gas transference varies directly as the internal excess pressure, it will consequently vary inversely as the diameter. Now, in Fig. 6, taking the origin at the point where the bubble vanishes, and measuring $x$ (time) horizontally to the right in days, and $y$ (diameter) vertically downwards in centimetres, we found that the gas transference was measured at any time $x$ by $-\frac{dy}{dx}$; hence $-\frac{dy}{dx}=\frac{k}{y}$ where $k$ is a constant, the graph of $\frac{dy}{dx}$

FIG. 10.




Gas transference through bubbles. Rates plotted with reciprocals of diameters. (1) Black H bubble of constant composition. (2) Golden H bubble of increasing dilution.

to $\frac{1}{y}$ is a straight line, and the curve of contraction is the parabola $y^2=D_0{}^2-kx$, where $D_0$ is the initial diameter—a result usually found to be the case. The equation of the particular curve in Fig. 6 is $y^2=121-\frac{121}{23}x$.

But, when a bubble partly composed of glycerine is exposed to water vapor and thereby progressively diluted, then the surface tension will increase; and the internal pressure will rise at a greater rate than would be due to diminution of diameter alone. The graph of the rates of gas transference, plotted with the reciprocals of the corresponding diameters, would no longer be a straight line. The next figure (Fig. 10) shows the graphs obtained in the case of (1) bubble of constant composition, (2) bubble of glycerine solution subjected to absorption of water vapor. In this second

case (see also Table IX) the rate of gas transference $dD/2$ (plotted as abscissæ) is increasing more quickly than the inverse of the corresponding diameters $1/D$ (plotted as ordinates)—a fact which could be explained (1) by an increase in the surface tension, with a resulting proportional increment in the internal pressure of the contracting bubble; and (2) by a more rapid percolation of hydrogen through the diluted film.

It is evident that further comparative experiments are necessary with more dilute films of constant composition before these effects can be differentiated. Preliminary attempts showed that a solution containing only 0.15 per cent. of ammonium oleate with 1.5 per cent. glycerine can give a fairly long-lived bubble (one such in hydrogen contracted completely in 28 days from 8 cm. diameter: see p. 745). But the maintenance of constant thickness is not easy, because with bubbles of such dilution even slight variations of temperature cause recurrent color changes; it is specially difficult to maintain the black stage.

No great alterations of temperature occurred in any of the above experiments, but distinct evidences of variations from this cause were noted on several occasions. The laws governing this factor have yet to be elucidated.

### ALTERATION OF THICKNESS BY CONTRACTION. SILVERY DISCS. CONSTANCY OF BLACK ZONE.

A contracting bubble that remains constant in weight will, of course, become thicker as the surface diminishes. The thickness will vary inversely as the square of the diameter, provided the capillary, viscous, and gravitational forces did not come into play. For small changes, on the simple theory, the rate of logarithmic increase of thickness will be twice the rate of logarithmic diminution of diameter. This is a property of the sphere that may be expressed as follows: When $S$ = surface, $T$ = thickness, $\rho$ = specific gravity of the liquid composing the bubble, then, since $S = \pi D^2$,

$$\text{Mass} = ST\rho = \pi D^2 T\rho$$

and as the mass and composition are assumed unaltered, this gives

$$D^2T = \text{constant, or } T \text{ varies as } \frac{1}{D^2} \quad \text{. . . . . . . . .} \quad (1)$$

*i.e.*, the thickness varies inversely as the square of the diameter, and is true for all magnitudes. Differentiating,

$$2TD.dD + D^2.dT = O, \quad \text{or } \frac{dT}{T} = -2\frac{dD}{D} \quad \text{. . . . . .} \quad (2)$$

which can be put in the form

$$d(\log T) = -2d(\log D) \quad \text{. . . . . . . . . . . . .} \quad (3)$$

Thus the rate of logarithmic increase of the thickness is twice the rate of logarithmic diminution of diameter.

In black bubbles increase of thickness can be observed if the contraction is rapidly effected by opening the closed bubble to the air, or by cautiously removing the air by suction; but the immediate effect is not to produce a colored bubble. What happens is that small silvery circular discs (see p. 721) break out over the surface of the black bubble, and these represent the aggregations of liquid resulting from the contraction, for they are much thicker than the black film through which they move. They very soon settle to the lower parts, and there slowly coalesce to a small graded colored area. This usually contracts in a short time to a much smaller zone, too thick to show color, and finally very little more is left than a small drop surrounded with a narrow silvery band on the otherwise black bubble. Large black bubbles contracting by gas percolation go too slowly for these effects to be observable, but the final result is the same: a drop of liquid slowly collects on the black bubble, and may in large bubbles grow sufficiently to fall off, after causing a progressive elliptical distortion.

Comparable behavior is shown when one or two drops of solution per minute are allowed to trickle into a black or partly black bubble. Colored streaks appear and pass downwards from places all round the supporting nozzle into which the liquid is fed; later on the streaks break up into colored discs, falling slowly by sinuous paths and with diverse motions. However, they all pass through the black portion, and after remaining for several minutes as a mass of distinct many-colored particles, form by coalescence a colored zone below round the drop. If the liquid is fed in more rapidly, the colored zone will rise to a certain extent, but, in single bubbles, a large area of black almost always remains. The feeding of the liquid may be cautiously increased almost to a stream; the bubble is then, of course, much disturbed at the boundary of the black zone, as well as elongated by the loading, and drops fall away in steady succession. The paths through the black zone may then become so thick as to be transparent threads of liquid, without any color in themselves, but causing colored rays and patches to flash outwards from their paths.

It was further observed that when a partly colored bubble

quickly altered in size, the black zone remained roughly constant in area, being independent of the extended or contracted surface. The thickness seemed to alter at the expense of the colored portion, which consequently changed in tint. A bubble is allowed to develop to blackness for about one-third of its surface, the remaining two-thirds grading from a silvery boundary at the black, through golden color to deep steel-blue. This state is reached in a few hours with a solution composed approximately of 3⅓ per cent. neutral ammonium oleate in 33 per cent. glycerine, with a slight excess of ammonia. Now gradually expand the bubble by a slight reduction of the external pressure. Meanwhile, the level of the black boundary, as well as the change of diameter, are observed. The colored area is seen to change from steel-blue to blue-purple through magenta and deep amber until almost the whole of it is a full golden color as a result of the diminished thickness, which, however, is still of the order of fifteen times that of the black. During this time the black boundary has risen slightly in level; but when the area of the black zone is calculated at successive stages, the value is found to remain constant to within a few per cent. All liquid must be well drained from the hanging bubble by leaving a drainage tube in contact with the drop position, during the preliminary development to partial blackness. Two sets of observations, showing the approximate constancy of the area of the black zone, while the colored portion is varying to a large ratio, appear in Table X below.

TABLE X.

| Whole Bubble. | | Black Zone. | Colored Zone. | Ratio. |
|---|---|---|---|---|
| Diam. (cm.) | Area (cm.)² | Area (cm.)² | Area (cm.)² | Colored: Black. |
| (i) 17.55 | 967.6 | 90.4 | 877.2 | 9.7 |
| 15.75 | 779.2 | 94.5 | 684.7 | 7.3 |
| 13.70 | 589.6 | 94.7 | 494.9 | 5.2 |
| 11.60 | 422.7 | 91.1 | 331.6 | 3.6 |
| 9.54 | 286.0 | 84.7 | 201.3 | 2.4 |
| (ii) 19.1 | 1146 | 77.7 | 1068.3 | 13.9 |
| 16.1 | 814 | 76.4 | 737.6 | 9.7 |
| 13.1 | 539 | 74.5 | 464.5 | 6.2 |
| 10.1 | 302.5 | 69.1 | 233.4 | 3.4 |
| 7.1 | 158 | 35.1 | 122.9 | 3.5 |

Thus, from the first four observations, the actual black area of the first bubble only varied some 2 per cent. from its mean value

92.7 cm.$^2$, while the colored-to-black ratio fell from 9.7 to 3.6, or some 63 per cent.: similarly the actual black area of the second bubble varied about 5 per cent. from its mean value 74.5 cm.$^2$, while the colored area fell from nearly 14 times to 3½ times the black area—a drop of over 75 per cent.

### ABSORPTION OF WATER BY BUBBLES COMPOSED OF OLEATE GLYCERINE SOLUTION.

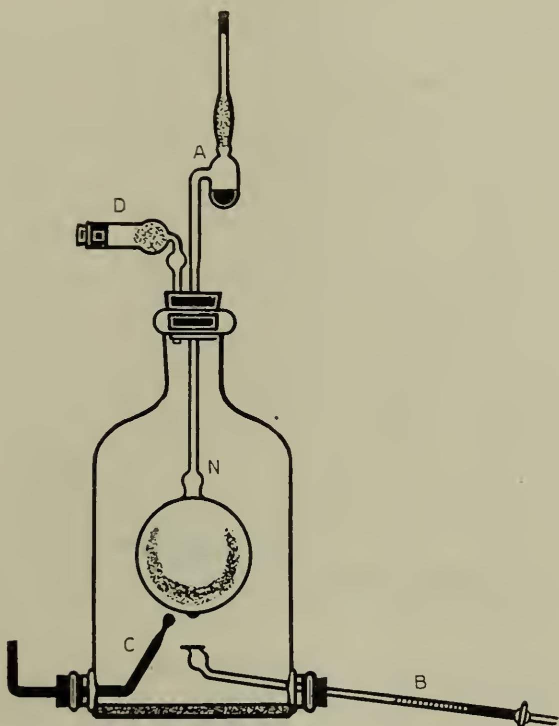
When boiled water is introduced into a vessel which holds a bubble composed partly of glycerine, water vapor is absorbed and the normal thinning of the bubble to the black stage is prevented. There is instead an increase in thickness, causing gradational changes of color: the bubble sags down from the increase in weight; successive drops accumulate and fall off, at first, maybe, two or three in a day, decreasing rapidly in number as the dilution proceeds, until when the soap-glycerine is reduced to 1 or 2 per cent. the interval between the drops grows into many weeks, and the drainage practically ceases. When very diluted the black stage is finally reached, and may remain, provided the temperature is steady; but usually much fluctuation of color takes place, the black even recurring many times.

The washings of several such bubbles were collected in a graduated tube, and periodically weighed and analyzed. In the case of a bubble of glycerine and ammonium oleate, the analysis for most purposes consisted simply in heating the liquid—in an oven at 90°–95° C.—until constant in weight. The contained glycerine and oleic acid were thus left practically in the same relative proportions as in the original bubble, water and ammonia being driven off. If necessary, the ammonia was separately estimated by Nesslerising. This is one advantage attending the use of ammonium oleate in such bubbles, as compared with the oleates of a non-volatile base like soda or potash.

The arrangements employed are shown in Fig. 11. The blowing-tube, *A*, with its nozzle, *N*, to carry the bubble, is supported in an india-rubber cork fitting the neck of a 10- to 12-litre tabulated "aspirator" vessel. *D* is a bulbed vent tube, and is packed uniformly, but not tightly, with cotton-wool moistened by glycerine. This allows any variations of atmospheric pressure to be equalized without endangering the purity of the internal atmosphere. *B* is the graduated collection tube fitted in the lower tubu-

lation: its nozzle, inside, is directly under the drops which accumulate on the bubble. Before opening the stop-cock on *B*, to draw off the accumulated liquid, the stopper in *D* is removed to allow the equalization of barometric pressure, otherwise the small quantities of liquid could not be smoothly withdrawn; alternatively, *D* may remain open. Before commencing observations any excess

FIG. 11.




liquid is removed from the bubble by drainage along the rod *C*. This is also done very effectively by a small bundle of very thin glass rods, about ¼ mm. diameter, tied together by thin aluminum wire: but the drawn-out glass rod, *C*, acts automatically when placed vertically just below the drop, for, as this grows, it descends by its own weight, and, enveloping the rounded end of the rod, drains down along the drawn-out neck, and the lightened bubble rises off the rod.

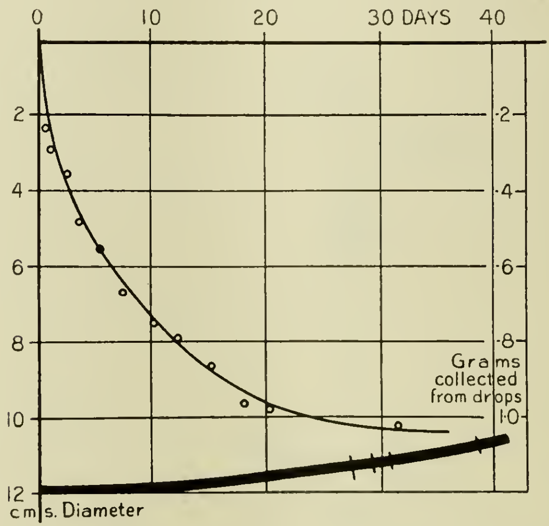
After the bubble has thus drained for several hours, the boiled

distilled water is run in. The collecting tube may be utilized for this by turning down the nozzle and tilting the vessel, or a separate inlet tube with stop-cock may be fitted.

In order to isolate the bubble from the soap solution in *A*, and prevent any distillation or intrusion of extraneous liquid, the reservoir in some experiments was removable. For this purpose a conical ground joint was made in the tube *A* above the india-rubber cork.

The contraction of the bubble is somewhat irregular, because

FIG. 12.




Air bubble over water remains colored. Contraction and condensation.

of the constantly varying thickness of the film, shown by the beautiful changes and gradings of color. In the case of an air bubble, the contraction is also relatively slow. Thus (Fig 12) one of 12 cm. diameter only diminished in forty days to 11 cm. A second one, of 21.4 cm. diameter, contracted in five months to 16.6 cm. A third one, of 15.8 cm. diameter, took a little over six months to contract to a plane film on the supporting nozzle. In wet hydrogen, however (Fig. 13), an 11-cm. bubble—under conditions of somewhat lower temperature—contracted completely in about three months; almost all this time, moreover, it was of sufficient thickness to show strong colors.

The form of the contraction curve of the hydrogen bubble is

fairly regular (considering the variations of thickness as shown by the color changes), and of similar form to that given by black bubbles of constant composition. Its collection curve, of similar type, in which the amounts collected by drainage are plotted as ordinates to the time of collection as abscissæ, is also shown in Fig. 13.

Similar contraction and collection curves are shown in Fig. 12 and Fig. 13 for air and hydrogen respectively. The left-hand vertical scales are for cms. in diameter for the contraction curves; the right-hand scales are for grams of liquid collected for the collection curves. The collection curve appears roughly as an image of the contraction curve, showing that, whereas the contraction is slow at first, increasing parabolically to the final disappearance, the condensation and drainage begins rapidly when the bubble contains concentrated glycerine, and falls off to zero as the dilution asymptotically approaches completion.

Careful measurement of such curves given by both air and hydrogen bubbles revealed them to be parabolic during the initial period before the surface became sensibly reduced by contraction. From this it follows that during this period the rate of collection is inversely as the total amount collected; just as in the contraction curves the rate of diminution of diameter is inversely as the diameter. The equation of this first portion of the drainage curve shown in the above figure for a hydrogen bubble is $y = 0.1787\sqrt{x}$, where $y$ is in grams, and $x$ is in days.

The approach to agreement between the observed and calculated values thus resulting is seen in the following table:

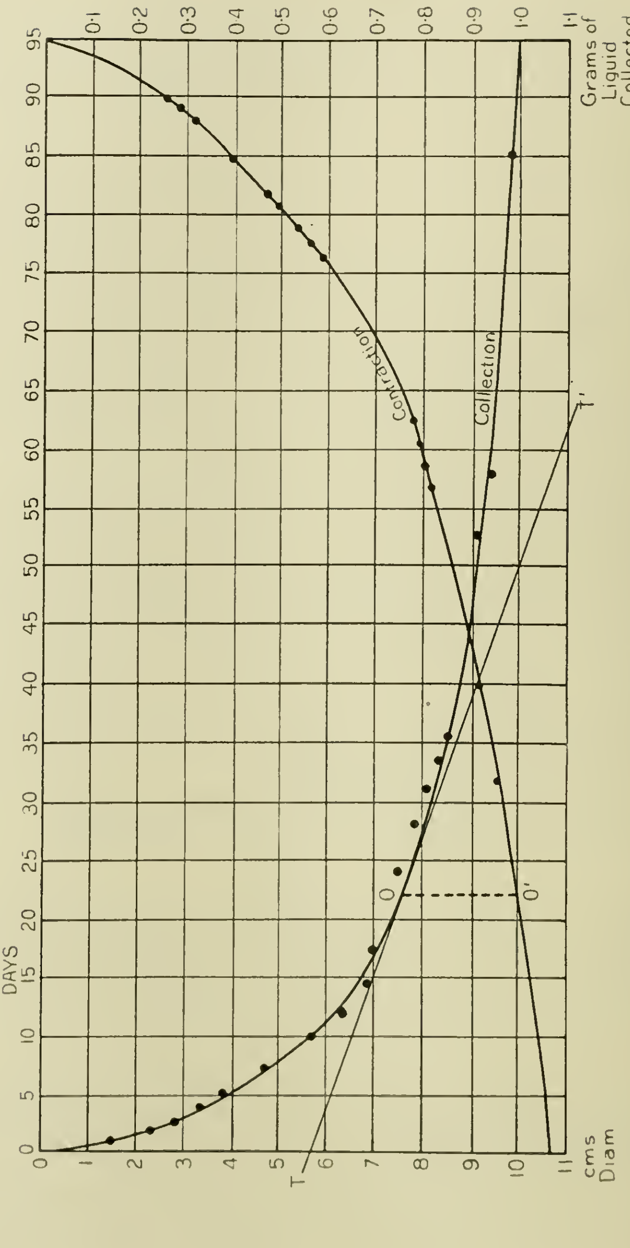
TABLE XI.

| | | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 12 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|
| $x$ Days | | | | | | | | | | |
| $y$ gms. | Observed | 0.18 | 0.26 | 0.305 | 0.36 | 0.45 | 0.52 | 0.57 | 0.62 | 0.66 |
| | Calculated | 0.18 | 0.25 | 0.309 | 0.36 | 0.44 | 0.51 | 0.57 | 0.62 | 0.67 |

In half a day 0.1 gram of liquid had been collected; in eight days 0.5 gram was obtained; but a total of 1.0 gram was only reached on the 95th day.

The corresponding expression in terms of mgms. from each sq. cm. of the bubble surface is $y = 0.514\sqrt{x}$. The result given by

FIG. 13.




Hydrogen bubble in hydrogen saturated with water vapor. Contraction and water absorption.

the bubble under similar conditions in air instead of hydrogen was $y = 0.554\sqrt{x}$ (see Fig. 12).

The final composition of the bubble is thus relatively very little different from water. As a confirmation of this the original bubble solution (5 per cent. of ammonium oleate, in 50 per cent. glycerine) was diluted thirty-three times with carefully prepared boiled distilled water. A bubble 8 cm. diameter was then blown from this solution. It lasted until completely contracted after exactly four weeks. During most of this time it was colored amber to purple; on three or four of the warmer days nearer the end (temperature about 10° C.) it reached a semi-black stage peculiar to these very dilute bubbles. Only one drop accumulated, caused by the shrinking of the bubble. This bubble has already been referred to in connection with gas transference through bubbles of graded dilution (see p. 737).

By investigating the condensation on unit area of the bubble, instead of on the whole bubble, a simple expression can be found that is applicable to the whole of the drainage curve, instead of only to the initial period of constant surface. The rate per unit area is, of course, found by dividing the weight of total drainage by the mean surface of the bubble over the period measured. This is most readily done by drawing a succession of tangents, $TT'$, to the collection curve (Fig. 13). The slope of these successive tangents along the curve gives the rates of collection at successive times from the whole bubble surface. The surface each time is obtained from the corresponding diameter, obtained by drawing the ordinates $OO'$ to cut the contraction curve. By dividing the total daily drainage rate given by the slope of the tangent $TT'$, by the corresponding surface at that time, there results the rate of condensation per unit area. The values thus accruing are set out in the first three horizontal rows of Table XII, with the corresponding day in the fourth row:

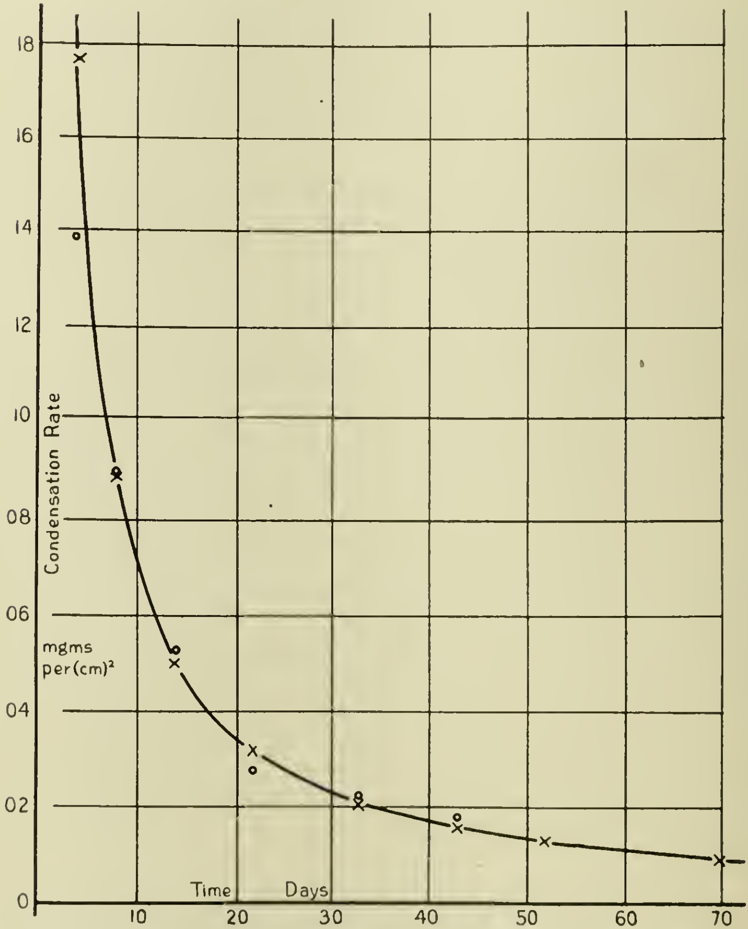
TABLE XII.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Daily rate of condensation | 0.049 | 0.031 | 0.0178 | 0.00885 | 0.0064 | 0.0047 | 0.0031 | 0.0015 |
| Surface | 353 | 346.3 | 333.3 | 314.2 | 283.5 | 254.5 | 227.0 | 153.9 |
| Rate per unit area × $10^4$ | 13.9 | 0.895 | 0.534 | 0.282 | 0.226 | 0.185 | 0.137 | 0.097 |
| Day | 4 | 8 | 14 | 22 | 33 | 43 | 52 | 70 |

By plotting the third and fourth rows as ordinate and abscissa, a new and more fundamental curve is obtained, which is shown in Fig. 14.

An examination of this curve shows that the alteration of the

FIG. 14.




Condensation on bubble in wet hydrogen. Rate of condensation, plotted to time.

rate of condensation *on unit area of the bubble* after the fourth day is practically hyperbolic as regards time. The expression most nearly fitting the curve is found (by plotting the results logarithmically) to be $xy = 0.705$, where $x$ represents the time in days and

$y$ the milligrammes of condensation on each square centimetre. Calculated points are marked "$x$" on the diagram, and values obtained from observations as above are marked "⊙."

By bursting bubbles in a weighed vessel, it was found that at the mean thickness which these bubbles maintain under the given conditions (shown by their color) they have a weight of very approximately 0.1 mgm. per square cm., and are therefore 0.001 mm. thick. Hence, in the equation just given, $y$ may also represent the weight (in milligrammes) condensed per day on each 0.1 mgm. of the bubble. The resulting values calculated for certain days are set out in the following Table XIII, together with the corresponding values obtained directly from the tangents to the original contraction curve:

TABLE XIII.

| | | 1 | 2 | 4 | 8 | 10 | 14 | 22 | 33 | 43 | 52 | 70 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $x$ = days | | 1 | 2 | 4 | 8 | 10 | 14 | 22 | 33 | 43 | 52 | 70 |
| $y$ = mgms. of condensation per mgm. of bubble | Calculated | 0.705 | 0.352 | 0.176 | 0.090 | 3.071 | 0.050 | 0.032 | 0.021 | 0.016 | 0.014 | 0.010 |
| | Observed | .. | .. | 0.130 | 0.088 | .. | 0.053 | 0.028 | 0.023 | 0.019 | 0.014 | 0.010 |

The calculated values are at first too high, but later vary slightly on either side of those directly deduced from observations (see Fig. 14).

The values in milligrammes per day, of the rate of absorption on unit area with an air bubble 15½ cm. in diameter, are given in the subjoined Table XIV. They were deduced from the weights of liquid collected in the periods named. The composition of the bubble was 50 per cent. of glycerine with 5 per cent. of ammonium oleate. This shows the rapid reduction in the daily rate of condensation occurring within a month—namely, from 0.452 mgm. at the beginning down to 0.003 mgm. at the end.

TABLE XIV.

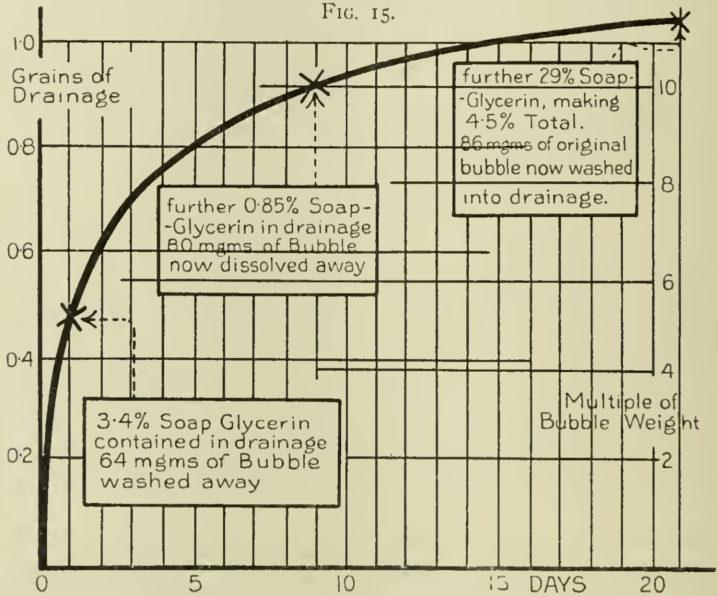
| Period. | Ratio of Water-vapor Absorption. |
|---|---|
| 1st day | 0.452 |
| 2–9 " | 0.073 |
| 10–21 " | 0.014 |
| 22–34 " | 0.003 |

ALTERING COMPOSITION OF THE BUBBLE DRAINAGE.

The variation of the composition of the liquid draining from the bubble, during the early portion of these experiments, is shown in the next two diagrams.

Fig. 15 shows the parabolic increase in the weight of the "drainage," with time; on a separate scale of ordinates, on the right-hand side, is marked the multiple of the original bubble

FIG. 15.




Altering composition of liquid collected from bubble when diluted by condensation of water. 16 cm. air bubble; 55 per cent. soap-glycerine.

weight equal to the amount of liquid collected. The three points marked are:

(1) 0.5 grm. of liquid in 1 day; being over 5 "bubble weights."
(2) 0.9 grm. of liquid in 9 days; being over 10 "bubble weights."
(3) 1.0 grm. of liquid in 21 days; being over 11 "bubble weights."

At each of these points the composition of the drainage, as well as the actual weight of the bubble which had then been washed away, were as follows:

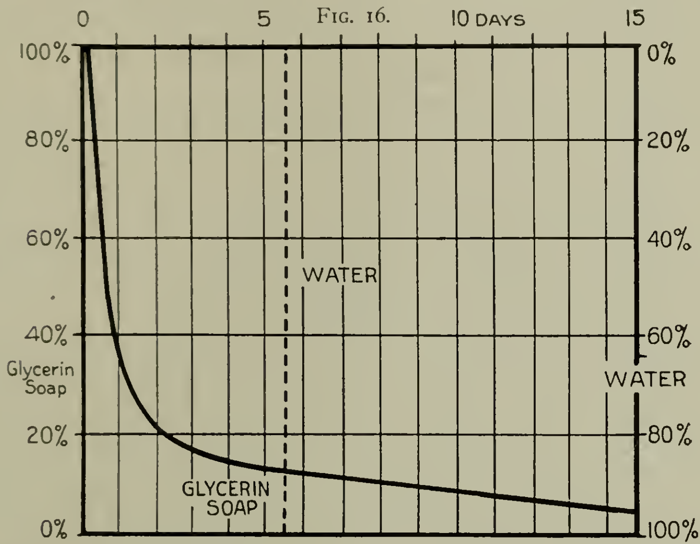
(1) 3.4 per cent. soap-glycerine; 64 mgms. of original bubble washed away.

(2) Further 0.85 per cent. soap-glycerine; 80 mgms. of original bubble now washed away.

(3) Further 0.29 per cent. soap-glycerine; 86 mgms. of original bubble now washed away.

In Fig. 16 the ordinates on the left show the decreasing percentage of soap-glycerine in the bubble, and on the right the consequent increase in the percentage of water, as the experiment proceeded. The number of days elapsing are again marked as abscissæ. The dotted ordinate shows, for example, that the bubble on the fifth day had nearly 90 per cent. of the original soap-

FIG. 16.




Alternating composition of bubble when diluted by condensation of water. 16 cm. air bubble.

glycerine replaced by water, and consequently only 10 per cent. of the soap-glycerine which was present in the original solution then remained; this was reduced on the fifteenth day to only about 3 per cent., but after this the rate of dilution was much less.

This intrinsic dilution curve agrees in form with that in Fig. 14, which shows the deduced rates of condensation per unit mass (0.1 mgm.) of the bubble with time. The one result follows from chemical measures of the alteration of drainage composition, while the other follows from the combined periodical observations of the weight of drainage and the contraction of the bubble.

The second part of this investigation dealing with Bubble-Complexes I hope to detail in a future discourse.

(W. J. Green, Esq., B.Sc., and J. W. Heath, Esq., F.C.S., Assistants of the Royal Institution, have aided in the course of the inquiry. [J. D.])

**On the Transmission of Speech by Light.** A. O. RANKINE. (*Proc. Physical Society, London,* August 15, 1919.)—Selenium changes in electrical resistance according to the light flux incident upon it. For several decades attempts have been made to transmit speech by using this fact. A beam of light is made to vary in intensity by the changes of pressure in a sound wave. This beam is received upon a selenium cell in circuit with a telephone receiver and a source of current. As long as the intensity of the light is constant so long is the current through the receiver constant. When, however, the intensity of the light changes, the resistance of the selenium changes and in consequence the current varies and the diaphragm of the receiver is made to move and to emit a sound wave.

There are two methods of making a beam of light fluctuate in intensity in accordance with the sounds of the voice. One is by controlling the light emitted by a source such as an arc lamp, by microphone action or otherwise. It is said that this method has been used with success in the German Navy over a distance of seven miles. The other method is to keep the source of light constant but to vary the intensity of the beam after it has started. The first method can, of course, be used only with artificial sources, while the second is applicable to sunlight.

A lens concentrates light upon a small spherical mirror. From this the light is reflected so as to pass through a second lens by which it is brought to a focus at which the selenium cell is placed. A grid with strips alternately transparent and opaque is put close to the first lens and between it and the mirror. A second grid of exactly the same dimensions is located close to the second lens, between it and the mirror and so that it coincides with the image of the first grid, image of opaque strip upon actual opaque strip. If the mirror is rotated about an axis parallel to the grid strips an opaque part of the second grid may receive the image of a transparent part of the first and *vice versa*. Thus no light would get through the second grid. The needle is made to turn about an axis by the lever which carries a gramophone needle. Thus, as the needle moves it tilts the mirror, which in turn shifts the image of the first grid falling on the second grid and varying quantities of light get through. The beam incident on the selenium varies the resistance, the current varies accordingly, and a sound is produced which is said to be a very good reproduction of speech. Some words, *e.g.*, "four" and "five" cause very loud sounds, while "two" and "three" produce weak sounds.

With this arrangement employing a seven-inch lens and a "pointolite" lamp the range is half a mile. More intense sources, of course, extend the range. Using the sunlight the faintest whisper was heard at a distance of one and a half miles.

The sluggishness of selenium in responding to changes in the intensity of light is a hindrance to greater efficiency. G. F. S.

# THE UNITED STATES NAVAL COMMUNICATION SERVICE.*

BY

CAPTAIN S. W. BRYANT, U. S. N.

Acting Director, Naval Communication Service, Navy Department.

Mr. Chairman and Gentlemen: I am sure that you will regret to know that Admiral Bullard, who was to deliver this lecture, is unable to do so on account of absence on duty in France; and as he has delegated me to substitute for him, I shall do the best I can to outline the activities of the Naval Communication Service.

The practical use of radiotelegraphy for communication with vessels at sea, in the development of which the United States Navy was one of the pioneers, resulted in the erection and operation, by the Navy, of a chain of stations along the coasts of the United States for communicating with Naval and merchant vessels. For several years the development was restricted mainly to material features with the result that no progress was made toward utilizing the radio facilities that were available in a well-thought-out plan, except, of course, for tactical uses in the Atlantic Fleet where its development was fostered and great improvements were made in the fleet itself so far as related to the tactical operation of naval units. There were a number of coast stations which, individually, were excellent so far as range and operation were concerned, but we had no organization to coördinate their operation with that of the fleet.

In 1912 the so-called Naval Radio Service was established, with Captain Bullard as the first superintendent. It was apparent that the material progress made in radio was at that time much further advanced than the administrative and operating features, so that efforts were concentrated immediately on a plan for the establishment of a service of communication that would serve the needs of our fleets and merchant marine to best advantage, both in time of war and in time of peace. We had a number of stations along our coast that were individually very good, and materially

* Presented at a joint meeting of the Institute and the Philadelphia Section, American Institute of Electrical Engineers, held Wednesday, October 15, 1919.

good, and, so far as their operation was concerned, were very good; but they were not connected up in such a way as to serve the interests of the fleet to the best advantage.

The plan outlined provided for continuous communication with our fleets and among the various sub-divisions of the fleets, as well as for the coördination of all naval communication facilities so as to provide a rapid and reliable interchange of information between all naval organizations afloat and ashore.

The advisability of combining all naval communication activities—that is, telegraph, telephone, cable, etc., and radio—under one head was soon appreciated by the Navy Department, and the name of this office of the department was changed from the "Naval Radio Service" to the "Naval Communication Service," and it was placed under the Chief of Naval Operations where, logically, it belonged. It consists of three main divisions, *viz.*, Atlantic, Pacific and Philippines, and each division is subdivided into districts.

The Director of Naval Communications exercises his authority through the division heads (coast superintendents), who, in turn, direct the district superintendents. So far as is practicable, the communication districts coincide with the naval districts, and all matters of an administrative nature within a district are handled through the Commandant of the district, to whom the district communication superintendent is directly responsible for the operation and administration of naval communications within the district.

The distribution of orders or instructions and the dissemination of information from the Navy Department, or from the heads of the various naval units, is thus provided for automatically. As an illustration of how this works, it is only necessary for the Secretary of the Navy to write one message, and if he wishes the entire naval service to receive it, that is automatically taken care of by the Communication Service. Each distributing office knows to whom it should send this message and from whom to expect acknowledgment. The acknowledgments are gathered in to the coast superintendents, and eventually to the communication office in Washington, and the acknowledgement is delivered directly to the Secretary. This same procedure may be followed by the commander of any naval unit for the distribution of messages through his forces.

I want to call your attention especially to the importance that other countries have attached to communications, because we feel that the people in the United States do not appreciate the importance of a satisfactory system of American world-wide communications; certainly not so much so as is done in foreign countries. The British have two routes to the East by radio in addition to their cables running out through the Mediterranean. The Dutch have undertaken a very elaborate program. They hope to have their radio station on the Island of Curacao communicate across to the Dutch East Indies. The French have also elaborated their plans, and the Belgians have in process of erection a radio station in Belgium that will communicate direct with the United States and with their possessions in the Belgian Congo. This, of course, is in addition to the cables that are largely controlled by the various countries. England has been especially active in extending her communications, and wherever her communications go trade follows.

A very valuable experiment was carried out by the Navy Department in May, 1916, in which all the naval stations within the continental limits of the United States were connected up to a central telephone switchboard in the Navy Department, and by means of which instant telephonic communication could be had between the various naval stations and the Navy Department, and also among the stations themselves. This was made possible through the assistance of the American Telephone and Telegraph Company, and its value later on, when this country declared war against Germany, was clearly proven. It was during this test that the Commandant of the Navy Yard, Mare Island, California, talked by telephone to the commanding officer of the battleship *New Hampshire*, which was then at sea off the Virginia Capes. The Commandant's remarks came by long-distance telephone from Mare Island to Arlington, where the transmitting station was installed, and from there out to the *New Hampshire* off the Virginia Capes. The greatest value derived from this experiment, aside from the knowledge that such rapid communication by telephone was available to the Navy Department, was the fact that all of the apparatus necessary was specially marked and could be placed in operating condition on twenty-four hours' notice. As a result, the interior communications of the country, so far as naval needs were concerned, were, on the outbreak of war, in

excellent operating condition, and made the task of the Navy Department, in communicating its instructions and orders to the various naval stations, a comparatively simple one at the time of the declaration of war.

We have one cable running from the United States direct to the continent of Europe that does not touch foreign soil between the United States and the European country, and that is a direct French cable from Cape Cod to France. All other cables touch in British territory or in the Azores. In the Pacific—we have one cable to the Philippines—all American; but the British have a cable running down from Vancouver to Australia by way of the Fanning Islands. The communication situation in the Pacific is a very serious one. The British control the cables on the east coast of Brazil from Buenos Aires up north. The Americans control them on the west coast and across to Buenos Aires. Every British possession practically is connected by some means of rapid communication with the mother country.

On January 1, 1917, the Naval Communication Service operated fifty-five radio stations, distributed along the coast of the United States and its possessions. Naval vessels were equipped so that they could recieve only one message at a time. Not all of the American merchant vessels were equipped with radio apparatus, some were equipped with poorly designed radio apparatus, and none of their radio operators was proficient in the procedure of communications during war. The Navy had only 1031 radio operators in its service.

The radio technical equipment of the Navy was as good as any in general use in the United States at the time, but the demands for communication proved that the technical equipment would have to be increased and improved to conduct all of the necessary communication demanded in time of war.

At the beginning of the war the demands for quick communication increased by leaps and bounds. It was found necessary to communicate with ships in all parts of the world, while at the same time to maintain long-distance communications between the Navy Department and our outlying possessions and expeditionary forces. It was necessary to maintain continuous and rapid communication between the Navy Department and Europe, South America, Central America, West Indies, Pacific Coast, Hawaiian Islands, Guam, Tutuila, and the Far East. The most important

centres of communications were at Cavite, P. I.; Hawaiian Islands, Canal Zone, Washington, D. C., and the capitals of the Allied nations in Europe.

To meet the demands for communication, the Navy's facilities were greatly and rapidly increased, and means were provided for collecting and disseminating information to every part of our coast and to naval vessels in Europe, South America, and the Far East.

The Navy took over and operated fifty-nine commercial stations. At the same time the several privately owned stations were closed, including all the stations operated by the amateurs, which were not necessary nor desirable for use during the war. Sixty-seven land radio stations were built by the Navy during the war, all equipped with the best apparatus, thus more than doubling its radio facilities on shore.

Naval vessels were equiped with improved apparatus, so that when the armistice was signed, battleships were able to receive four messages simultaneously and transmit three. The Commander-in-Chief of the fleet could talk to the captains of vessels in the fleet; while, at the same time, the various ships of the fleet could communicate with one another. In addition, and at the same time, airplanes could communicate with their respective battleship units. None but a naval officer can appreciate the value of such a system or how much such a system facilitated the freedom of movement of the fleet.

The Navy Department equipped all American merchant vessels with modern apparatus and furnished operators for them, so that these merchant ships could receive messages at any time of the day and transmit messages at long distances in case of distress.

The Navy had to train most of its radio men because the radio amateurs in this country were soon incorporated in the army and navy. These operators were trained at Harvard. In June, 1917, there were 350 students under instruction. When the armistice was signed there were 3400 men under instruction, and operators were being graduated at the rate of about 200 a week. A total of about 7000 operators completed their training. In addition to the radio operators, it was necessary to train officers for communication duties on board the ships. At the time the armistice was signed, each ship of the Navy had a communication officer, and each merchant ship had a chief petty officer

who performed communication duties and, therefore, relieved the master of the ship from a very vexatious duty.

The year before the war there was handled approximately 125,000 dispatches from the Navy Department. These dispatches averaged about 25 words each.

From April 6, 1918, to April 6, 1919, approximately 1,000,000 dispatches, of an average of about 30 words each, were handled from the Navy Department alone. Some of these dispatches, on account of the necessity of broad-casting, were sent twice in order to insure their delivery.

As it was assumed that the use of radio apparatus by ships at sea enabled German submarines to ascertain more or less accurately the movements of such ships, communication by radio from merchant ships was discontinued except in case of emergency. Men-of-war were cautioned not to use their radio apparatus unless necessary. However, it was very necessary that information should be received on shore regarding the movements of the enemy, and that the consequent orders to ships at sea should be transmitted expeditiously. Therefore, in order to direct the movements of convoys, and to transmit information to naval vessels regarding the enemy, and to issue orders to both merchant ships and naval vessels, a comprehensive system of transmission from shore was organized with the view of making it unnecessary for ships at sea to use their radio apparatus.

All merchant vessels listened for their orders from certain designated shore stations during certain hours of the day. These messages were sent by high-power and low-power stations, depending on the distance of the ship from shore. Naval vessels intercepted messages from shore stations at all hours of the day. In order to send a message to a naval vessel at sea, it was necessary only to transmit from certain shore stations on a designated wavelength. It soon became evident that this was a very sure means of communication. Many times, fifty or sixty messages were transmitted to sea simultaneously, all destined for different classes of vessels, and they were received by ships in accordance with the plan.

The foregoing system demonstrated that ships at sea could be warned of mines and submarines, and their movements directed without the necessity of their using their own radio apparatus.

The system was automatic to such an extent that it was almost certain that a vessel could be reached at any time.

In order that errors in this system might be eliminated and in order that the Navy Department might be informed of the movements of vessels, there was established a Shipping Information Service. A confidential bulletin was published showing the movements of all United States vessels and as many foreign vessels as could be obtained. This information was collected from all the important ports of the world and the data printed in a booklet. This service grew to such an extent that the booklet now contains the names of approximately 12,000 vessels, their arrivals and departures, character of cargo, and destinations, and is of much value to shipping and business interests. It is the present plan to have the Naval Communication Service continue this publication until Congress makes other disposition for its publication.

In order to check the radio work of merchant vessels, a comprehensive system of inspection was organized, both in the United States and abroad. Every merchant vessel that came into port received a thorough inspection of its radio apparatus, and the radio operators were examined and thoroughly instructed. Any mistake indicated in the log-books was investigated and the operator instructed as to the correct method of handling such cases.

Besides inspections, the Navy maintained a comprehensive system both at home and abroad of radio repair stations. Any radio apparatus on board ship which had broken down was repaired when the ship came to port.

It soon became evident that if the commander of the United States forces in Europe was to maintain close touch with all of his forces, it would be necessary to establish and control a complete system in Europe. To this end cables were laid and land wires and radio stations constructed in France, England and in Italy. The Navy used a great many of these land wires and cables that were constructed by the Signal Corps of the Army. Close coöperation was maintained with the Allied communication services with the view of utilizing their systems whenever possible and with the view of avoiding duplication of effort.

During the war it was found necessary to maintain radio communication between the United States and our naval and military forces in Europe and in other parts of the world.. In October,

1917, the Allied military and naval officials had a conference to determine the best methods of operations that were to be used in maintaining communication between the United States and Europe in case the cables were either cut by the enemy or otherwise placed out of commission.

It was decided that the United States would use the radio stations at New Brunswick, Annapolis, Tuckerton and Sayville for transmission purposes; but at this time none of these stations was in reliable communication with Europe at all times of the day and year. Therefore, it was necessary to increase the power of Tuckerton and Sayville and to place more modern apparatus in New Brunswick. The radio station at Annapolis had not been completed, and orders were given to rush the construction. There were only two transatlantic receiving stations, *viz.*, one at Chatham, Mass., and one at Belmar, N. J.

In Europe the only radio stations available for use in transoceanic communication were those at Rome, Italy; Lyons, France; and Carnarvon, Wales. Of these stations, the one at Lyons, France, was the only one able to communicate satisfactorily with the United States.

None of these stations was equipped with high-speed apparatus, and none was equipped in such a way as to avoid intentional interference from radio stations in Germany and the systems of operation and control were not such that large volumes of traffic could be handled.

At first it was decided that all messages from Europe destined to the United States would be sent during certain hours of the day from Lyons, and if possible from Rome and Carnarvon. Messages from the United States destined for Europe were to be transmitted from New Brunswick, Sayville, Tuckerton, and as soon as possible from Annapolis during the remaining hours of the day. In the beginning this system was capable of handling only a comparatively few important messages. Later, when it became evident that the Germans were making some attempt to cut cables off the coast of the United States, it was decided to erect another high-power station in France. In the meantime, improvements were being made at Lyons and Rome. The key was in the Navy Department for transmission from Sayville, Tuckerton, New Brunswick and Annapolis.

New improvements in organization and operating methods

were made both in the United States and in Europe, resulting in a centralized control of four United States high-power radio stations from the Navy Department. A receiving station was constructed at Bar Harbor, Maine, which proved to be one of the best receiving stations in the United States. The receiving stations at Chatham and Belmar were not used, as they were not necessary. The power of the radio stations at Tuckerton, Sayville and New Brunswick had been increased. At the time the armistice was signed, the United States system was capable of handling several thousand words per hour, and the whole transoceanic system was able to transmit and receive messages simultaneously without fear of intentional interference from Germany's high-power radio stations. Also, just before the armistice was signed, experiments in high-speed transmitting and photographic reception had begun. Had it been necessary, the transatlantic radio service would have been capable of handling all of the Government traffic between Europe and the United States.

When the United States entered the war it was noticed that the Central Powers were conducting a comprehensive scheme of propaganda by wireless. Counteracting this were the systems operating from France and England. The United States had no means of distributing American news throughout the world. Therefore, it was decided to use the transoceanic system of the Navy to distribute news of a reliable nature from the United States. The transatlantic stations transmitted this press news to Europe and South America. Naval vessels in South America received the press and distributed it to the local papers in those countries. The European news was distributed by Admiral Sims' headquarters and redistributed to the various capitals of Europe, including points in Russia. The Central American news was broadcasted from the Navy's high-power station in the Canal Zone, and was received in the northern part of South America and Central America and Mexico. News was distributed to the Philippines, Japan, China and Siberia, through the Navy's transpacific high-power stations. These reports were received in the Philippines, Shanghai, Vladivostok and Japan, and distributed to the local papers in those countries.

During the war it was found exceedingly difficult to locate persons in the United States who were using radio apparatus unlawfully. Also, when the German submarines began opera-

tions off the United States in June, 1918, it was found that, although the radio signals of the submarines were intercepted by naval radio stations along the coast, there were no efficient devices by which the exact location of the submarines could be ascertained from their radio signals.

It was found that enemy submarines used their radio apparatus promiscuously, and that they operated in pairs in order that they could fix the position of their prey by means of bearings. Such procedure necessitated the use of radio.

In order to counteract the foregoing situation, the Navy developed a comprehensive system of radio compasses, by means of which the bearing or direction of the enemy's signals could be obtained. Also, all signals were copied so that every time a message was sent the Navy could trace it. Shortly afterwards, it was noted that the submarines did not use their radio, and it is believed that the Navy's shore radio compass system robbed the enemy of a vital weapon, as the radio compass not only made it dangerous for the enemy to use their radio for communication purposes between one another, but also prevented them from using it for sending decoy distress messages.

Later the Secretary of the Navy "in a plan to hasten the progress of troopships" authorized the construction of fifteen additional radio compass stations, making a total of thirty-four on the Atlantic and Gulf Coasts. These radio compass stations were at harbor entrances and enabled ships at sea to enter port without consequent delays due to thick weather and fog. This was a very important item in the war as every minute counted in a ship's voyage.

After the armistice was signed, the Secretary authorized the construction of twenty-four more radio compass stations, which made a grand total of fifty-eight in the United States, and which are to be used as aids to navigation during time of peace.

The technical bureaus of the Navy Department kept pace with the operating departments in their advance in the art of radio communication and in coöperation with the radio engineers of the country accomplished some remarkable developments in radio during the war.

Efficiency in high-power transmission was increased from 30 to 90 per cent. Not only was greater efficiency arrived at with lower cost, but the power of transmission was increased. For

example, the radio station at Bordeaux, France, which is being constructed under the auspices of the Navy Department, has an input of 1000 kilowatts. Its range is estimated to be 12,000 miles. It has eight 820-foot towers.

There was an increase in speed of transmission from about 30 words a minute to 100 words a minute in actual practice, and to about 300 words a minute in prearranged tests. One of the difficulties in high-power stations was the sleet on the antennæ. Methods have been arrived at by which sleet is now prevented from accumulating on the wires of the antennæ.

The valve has been developed from a non-oscillating detector to an oscillating transmitter. It is possible to receive radio signals by the beat method and to transmit signals from the valves at comparatively long distances. The valve is used also in the transmission of speech, and is very efficient for this purpose.

Another feature of valve transmission is that it permits of very sharp tuning, which in turn permits simultaneous transmissions from a great many stations. It is believed that it will be developed in the future to such an extent that it will replace most of the existing low-power transmitters.

Another feature of the valve is that its life has increased from 5 hours to over 5000 hours, which is a very important item in the expense.

Great improvements have been made in receiving apparatus in that they are more selective, and directive receiving has increased in efficiency from 0 to 75 per cent. The old type of overhead antenna is being rapidly replaced by the use of balanced loops and underground wires, radio phase changers, and low horizontal wiring.

It is now possible to receive signals on submarines while submerged at depths of 20 feet, from shore stations, aircraft overhead, and ships afloat. This system was used to advantage in directing our submarines off our coast when they were hunting for enemy submarines.

Another improvement has been made in the radio compass, which was used at first for detecting the positions of enemy submarines, but is now developed into an aid for navigation. With properly trained personnel, the Navy is now able to give ships their positions without any large error. This will be a great boon to our merchant marine because it eliminates the delays

caused by fog and thick weather, besides making navigation generally more safe along the coast.

An interesting experiment was carried on in San Francisco from the naval station at Goat Island during a reecnt visit of the Pacific Fleet to that port. A radio telephone was installed on Goat Island, in San Francisco Harbor, and connected by land wire to the telephone company's switchboard in San Francisco. A man on board ship was thus able to talk to his friends on shore in any part of the city. Also, this friend on shore could call up the ship from his home. This means of communication with the fleet became a popular fad in San Francisco during the stay of the fleet.

The foregoing developments are just an indication of the possibilities of the use of radio communication in the future.

If the general public of the United States is to receive the best sort of service in radio communication, it will be necessary for some central controlling agency to regulate the matter. There are so many different private services that naturally wish to have radio communication that the only solution is to have it regulated by some central authoritative agency. For example, we have heard that a man in Waco, Texas, desires to build a radio station to communicate with another radio station in Boston. This service is for his private use. Another man desires to communicate between Detroit, Mich., and Los Angeles, California. This is also a private service. Another man wishes to communicate between Philadelphia and New York. This is a private service. Another man wishes to communicate between Chicago and St. Louis. This is a private service. Multiplicity of such private service will soon demonstrate to the public that the best use of radio communication is being handicapped. The man who has the circuit from Waco, Texas, to Boston may receive interference from the man who has a circuit from Detroit to Los Angeles. The man who has the service from Chicago to St. Louis may receive interference from the man who has a service from Detroit to Los Angeles. Unless there is some central regulating body which has the power to regulate the use of radio in accordance with the development of the art, it is believed that the future demand for radio communication will be limited, and in consequence the art will not progress as much as it would if it were properly fostered and regulated. The extensive use of radio in European countries

by the Allied armies and navies with the consequent experience gained has demonstrated this fact.

To illustrate how a naval communication district acts, I should like to take as an example the Third Naval District, which extends from Rhode Island to Barnegat Inlet, and in which there are eight coastal radio stations which are located as follows: Montauk, L. I.; Fire Island, L. I.; Rockaway Beach, L. I.; Sea Gate, N. Y.; Bush Terminal, N. Y.; Navy Yard, N. Y.; Mantoloking, N. J., and New London, Conn. There are also five radio compass stations located as follows: Montauk Point, L. I.; Fire Island, L. I.; Rockaway Beach, L. I.; Sandy Hook, N. J., and Mantoloking, N. J. These radio and compass stations are all controlled from one Central Control Station, located at No. 44 Whitehall Street, New York City, at which place are also the offices of the District Communication Superintendent. Direct wires from each of these stations lead into the Central Control Station, and by means of a plug-board arrangement similar in type to that used by the telephone companies, any one of these stations may be used as a transmitter by the operator on watch at the control station.

The control station is divided into a number of booths which are magnetically shielded from one another and which contain receiving apparatus of the most up-to-date type. Each booth is given a wave-length which the operator on watch must guard. There is no transmitting apparatus at this control station, all transmitting being done by means of distant control through one of the other stations mentioned above. Therefore, if the operator on watch at 600 metres receives a call and desires to answer, he promptly plugs in on a wire to any station he may decide to use and transmits via that station. He is listening all the time to what he is sending and should he hear a distress signal, he could instantly stop and give his attention to the distress call.

A chief electrician (radio) is on duty at this control station as supervisor of traffic. On his desk he has a receiver which enables him to listen in and keep check on the traffic being handled on the various wave-lengths, and, from time to time, gives orders to the various operators and stations so as to avoid interference. Such a system of supervision was found necessary in order to overcome some of the difficulties brought about by the large increase in radio traffic about the port of New York. The excellent manner in which this system functions locally about the port

of New York is another illustration of the neecssity of radio supervision by one central controlling agency.

All the stations in the Third Naval District, however, are not at all times controlled from the Central Control Station. If traffic warrants it, some outlying station, such as Montauk or Fire Island, is given orders by the supervising electrician to handle traffic independently. At such times, the outlying stations are practically acting as agents for the control station.

The great advantage, besides regulating radio traffic and cutting down the amount of interference, is that should any of the stations in the district, or the control station, hear a distress call, or any other emergency arises, the control station can immediately notify all stations to stop sending, which will leave the air clear so that the emergency may be taken care of. The ability to stop all stations in the district instantly is an absolute necessity in time of war and proved itself of much value during the time the German submarines were active along the American coast.

The radio compass stations are controlled in a manner similar to the radio transmitting stations in the Third Naval District. Each compass station in the district is connected with the Compass Control Station at No. 44 Whitehall Street, New York City (which is in the same room with the Radio Control Station) by means of direct wires. The compass stations are not equipped with transmitters, and, therefore, never work independently of the Control Station, but forward all their bearings to the supervising operator. The procedure followed by a vessel which desires her position is as follows:

The vessel calls "NAH," the call letters of Navy Radio New York, signing off with the ship's call letters, followed by the international radio abbreviation "QTE," meaning, "What is my true bearing?" or with "QTF," meaning, "What is my position?" When this signal is heard by the radio operator on watch, the compass supervisor is immediately informed and he, by means of a master key which controls all wire circuits to the compass stations simultaneously, notifies the compass stations that the ship is calling for bearings and gives the wave-length by which the ship will transmit. The radio operator in the meanwhile has acknowledged the ship's call and instructed the ship to transmit by sending dashes on whatever wave-length he may

specify. The compass supervisor, who also listens in to the radio signals, gives a signal on the wires leading to the stations when the ship commences to send dashes, or, in other words, tells all stations, "There he is now." All five stations in the district then take bearings on the ship which is transmitting, and when the supervisor calls for same, forward them to the Control Station on the wire. The supervising operator enters upon a specially prepared radio blank the bearings obtained, and before transmitting these bearings to the vessel plots them on a chart specially prepared for this purpose, noting whether a good fix was obtained. If the bearings obtained were good, he turns over the radio blank with bearings on it to one of the radio operators, who, in turn, transmits it to the vessel. If the bearings obtained are poor, as shown by plotting them on the chart, the compass supervisor informs the radio operators, who request the vessel to repeat, in order that a new set of bearings may be obtained.

The average time required to obtain the bearings and forward them to a vessel is between three and four minutes. In thick weather there are many calls for radio bearings, and the five stations in the Third Naval District are kept busy. It is always the desire of the supervising compass operator to obtain bearings from as many stations as possible, in order to note whether they all check. If bearings can be obtained from three or four stations and these bearings all intersect at one point, he is then reasonably certain that the bearings obtained are accurate.

A means of checking radio compass stations has been devised in the Third Naval District and placed in operation there. By close coöperation with the Navy Route Office, Custom House, New York, where all masters of vessels call for information regarding shipping, much data has been obtained which has proven itself useful in compiling efficient curves and records of the behavior of the radio compass stations. This system has been developed in order to be able to tell at a glance how each station behaves and what the average error is in 20-degree sectors. It has been found that in some sectors the compass may read minus, while in another sector it may read normal or plus. With such data on hand it is comparatively easy to make tests and recalibrate stations, as it is already known in what directions and by how much the station is off. Such a system is especially valuable in view of the ease with which a radio compass may be influenced

either by change in a position of the apparatus, slipping of the compass dial, or due to disturbing influences in the vicinity of the station, such as telephone wires, etc.

I just want to say a word in regard to the personnel employed at these radio compass stations. You have seen a photograph of the kind of place they have to perform their duties in, and most of the stations are in similar isolated places. In the winter time, especially, there is quite a strain on the operator, and they deserve much credit for the service they have rendered. They have to sit quietly in a small hut on some lonesome beach, listening continually for vessels on which to obtain bearings, in order that navigation may be made less dangerous and life and property at sea be safeguarded. One of the greatest drawbacks to the present radio compass installations is that so much depends upon the human element. What is badly needed, and which will undoubtedly be developed in the very near future, is an indicating instrument for use in connection with loops. When such an instrument has been devised, it will be quite simple and more accurate to obtain bearings on any radio station. At present very much depends upon the operator's acuteness of hearing and judgment, and as long as such is the case, absolutely perfect bearings cannot be guaranteed.

I want to call attention to the flexibility of the Naval Communication Service and cite as an instance the flight of the NC-4. A message was transmitted from the Navy Department to the plane during its transatlantic flight, a reply was received from the plane, and this reply was transmitted to London, Paris, San Francisco and the Canal Zone, and an acknowledgment received from those stations, all within three minutes of the time of beginning the first transmission to the plane from the Navy Department. Of course, every one was very much interested in the flight and the stations were all very keen to give the very best service, but this remarkably rapid operation was even a little better than we had anticipated.

During the Peace Conference the Naval Communication Service handled all of the radio communication for the American delegation. During the past summer, at the request of the American Relief Association, the commander of our naval forces in European waters put the Naval Communication Service personnel on land lines, handling the Relief Association messages through-

out certain countries in Europe, and they are now handling that service and will continue to handle it until peace is finally proclaimed. This involves a complete communication system in central Europe, and gives the Navy, as well as the American Relief Association, a communication system between its London headquarters and Paris, Germany, Poland, Belgium, Italy, Austria-Hungary and Turkey.

The Communication Office of the Navy Department has handled during the last year the following messages:

| | |
|---|---|
| Sent to Europe by Navy Department | 16,910 |
| Sent to Europe by other Departments | 3,645 |
| Sent to home waters by Operations | 22,870 |
| Sent to home waters by bureaus and other departments | 351,516 |
| Received from Europe by Navy Dept. for Navy | 23,034 |
| Received from Europe by Navy Dept. for other depts. | 3,893 |
| Received from home waters to Operations | 49,950 |
| Received from home waters to bureaus and other depts. | 717,313 |
| TOTAL | 794,190 |
| Grand Total | 1,189,131 |
| Grand Total number words at 60 words per dispatch | 71,347,860 |

The foregoing total was handled as follows:

| | |
|---|---|
| By Costal Radio | 1,621,542 |
| By High Power Radio, Transatlantic and Continental | 16,215,423 |
| By Leased Wire, Western Union and Postal | 53,500,895 |

The above figures are exact, except the Bureau dispatches, which are approximate and are based on the daily ratio of bureau dispatches to others during the last five months since an accurate record has been kept.

You will note that there were approximately 71,350,000 words handled by the Naval Communication Service. The high-power radio handled approximately 16,000,000. The leased wires handled approximately 53,000,000, and the coastal stations handled about 1,500,000.

During the period of demobilization a very large commercial business was done with returning transports, some of the larger transports handling fifteen hundred messages in a single month, the men wishing to send messages to their friends at home. In order to encourage this use of radio by returning troops, free

service was accorded military personnel and civilian employees of the Government in so far as the ship's sending charges were concerned. Of course, this served to increase the traffic and afforded the men a chance to communicate with their families.

During the period of the war and until April 1, 1919, practically no revenue was obtained from traffic with foreign ships. This was due to the fact that up until that time no personal messages were allowed and Allied countries, with one exception, had agreed to handle messages for Allied ships free of cost as regards shore station tolls. Pre-war charges were placed in effect for United States shore stations on April 1, 1919, and foreign ships were charged regular shore station tolls.

Owing to the congestion of the Pacific cables, the Naval Communication Service reopened the transpacific circuit to Japan and the Philippines on December 19, 1918. This service, so far as Japan was concerned, took the place of the service inaugurated by the Marconi Company about three months previous to the outbreak of the war, the Navy carrying out the agreement as to tolls between San Francisco, Pearl Harbor, and Japan. Owing to the large volume of Government business this traffic was restricted to full-rate business only.

In November, 1918, the telegraph and telephone division was in charge of a lieutenant-commander, with five officers, twelve chief petty officers and an enlisted personnel of about one hundred and thirty. The telegraph system of the Navy Department at that time included wires from Galveston, Texas, to Bar Harbor, Maine. The leased telephone wires of the Navy Department extended from Norfolk, Virginia, to Portsmouth, N. H., there being seven private telephones from the Department to New York alone. The telegraph office of the Navy Department was handling 4000 messages a day and the Navy telephone exchange was handling 18,000 telephone calls per day.

At the time of the armistice, the Daily Shipping Bulletin, which I think I referred to previously, was being printed on a hand press and about 300 copies a day were being distributed. It was very roughly made up and had not assumed any permanent form. The personnel consisted of three officers and about 100 enlisted men.

By July 1, 1919, the circulation of the Daily Shipping Bulletin had grown to nearly 2000 copies a day. It was being printed

on a power press and had assumed a standard form. Of its total circulation nearly 1400 were commercial firms, such as shipping companies, marine underwriters, ship brokers, exporters and importers, press associations, etc. The Bulletin contained the names of 12,500 ships with news of their latest movements and the record of nationality, register, tonnage and cargo. The popular demand for the Bulletin is growing daily and its success as a government activity is assured. Arrangements are under way to establish a permanent civil service personnel for the operation of the Bulletin to replace the enlisted personnel whose enlistments will expire or whose service in the reserve force will terminate.

The censorship of all cables was controlled from this office through the following branch offices:

| | Personnel | |
|---|---|---|
| | Nov. 11, 1918 | June 30, 1919 |
| Brazil | 9 | 0 |
| Guam | 5 | 0 |
| Guantanamo Bay | 3 | 0 |
| Galveston | 17 | 0 |
| Honolulu | 17 | 0 |
| Cape Haitien | 1 | 0 |
| Key West | 9 | 0 |
| Lisbon | 1 | 0 |
| New Orleans | 12 | 0 |
| New York | 760 | 78 |
| Paris | 1 | 0 |
| Ponce | 3 | 0 |
| Panama | 8 | 0 |
| San Antonio | 7 | 0 |
| St. Croix | | |
| Havana | | |
| San Domingo and Puerta Plata | 5 | 0 |
| San Diego | 1 | 0 |
| San Juan | 9 | 0 |
| San Francisco | 151 | 0 |
| St. Thomas | 3 | 0 |
| Seattle | 5 | 0 |
| London | 1 | 0 |
| Chief Cable Censor | 103 | 4 |

On April 18, 1919, by executive order, the censorship on all cables was removed from all messages except those addressed to or from German territory. This act greatly reduced the activities

of the section and all branch offices except Washington and New York were closed. On July 23, 1919, all censorship of cables was removed and this section rapidly completed its most important duties.

In closing, I would like to say that we are trying to get the people in the United States to appreciate the value of communications, and we feel that every foreign country of consequence—England, Germany, France, Italy, Belgium, and Holland—appreciate the great importance of communications and of having a system of communications over which they have control; but it seems that the people in this country have not fully realized the benefits to commerce that will naturally follow if we do have an efficient communication service with foreign countries, or such a service to those countries with which American commercial interests wish to do business.

In the Pacific, one of the most vital considerations at present is getting reliable news from the Far East into the United States, and from the United States into the Far East. The attitude in China toward Americans is one that could not be better; their feeling, as expressed to me by people who have recently been in China, is one of the deepest friendship for us, and the question of establishing communication with them and of getting reliable and recent news to and from China is one of the most important questions of the day, and I wish to emphasize the point that if there is any way of impressing upon every American the necessity for communications and the interest that the United States should take in it and in its development, and in fostering the development of high-power radio or cables, it is a patriotic duty to do so.

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**Manufacture of Acetic Acid from Acetylene.**—In an article on organic mercury compounds F. C. WHITMORE (*Chemical Bulletin*, Chicago, vol. vi, pp. 164–165, 1919) reports that acetic acid is now made from acetylene with success on a commercial scale. Acetylene reacts with mercuric salts to form an organic compound of mercury, the exact composition of which is uncertain. Acids react with this compound to form acetaldehyde. In the commercial process acetylene is passed through a series of baths containing mercuric sulphate, sulphuric acid, and glacial acetic acid. The supply of water is so regulated that only that required for the reaction is present. Acetaldehyde is evolved in a steady stream, and is then oxidized to acetic acid by means of the oxygen of the air in the presence of a catalyst. J. S. H.

# A MULTIPLE-TUBE MANOMETER.*

BY

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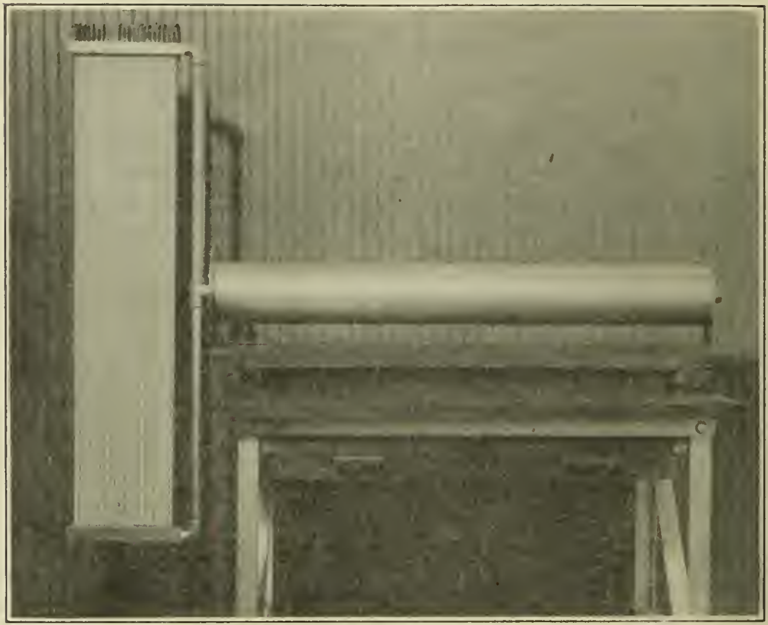
*Preface.*—For the measurement of pressure distribution over aerodynamic models, it is convenient to have a manometer composed of numerous tubes arranged side by side and adjustable to various sensibilities. Figs. 1 and 2 give the external appearance of such an instrument developed in the Aerodynamical Laboratory of the Bureau of Construction and Repair, early in 1917.

*Description of Instrument.*—A cylindrical alcohol tank rotatable in axial bearings carries at one end a tee-shaped pipe which supports a bank of twenty glass tubes mounted on a graduated metal plate. The glass tubes are sealed in sockets opening into the bottom branch of the tee, and are extended above the top branch by brass nipples for connection with rubber tubes leading to the aerodynamic surface to be studied. As the bore of the glass tubes is $^3/_{16}$ inch, the alcohol tank is made 50 inches long by 6 inches in diameter, so that the change of hydrostatic head therein is very slight when the meniscus in the tubes travels a distance of two feet, this being the probable range required in general wind tunnel use. For the measurement of large pressure differences the tubes are set vertical; for slight differences they are set on a slope of 1 in 10 by rotation of the system in its bearings; and to prevent shifting of the zero in this operation the surface of the alcohol is kept in the axis of the instrument by timely adjustment. By means of the leveling screws the axis of the tank is set horizontal, and the whole apparatus can be given a slight rotation, if need be, to correct the slope of the inclined tube-holder. The clamping of the tube system is effected by means of the spring latch shown screwed to the baseboard and engaging a slot in the flange at the near end of the tank. Three such slots are provided; one for holding the tubes vertical; one for holding them on a 1 to 5 slope; and a third for holding them on a 1 to 10 slope. The graduations on the plate back of the glass tubes, when vertical, read in inches and tenth inches of water, positive and negative.

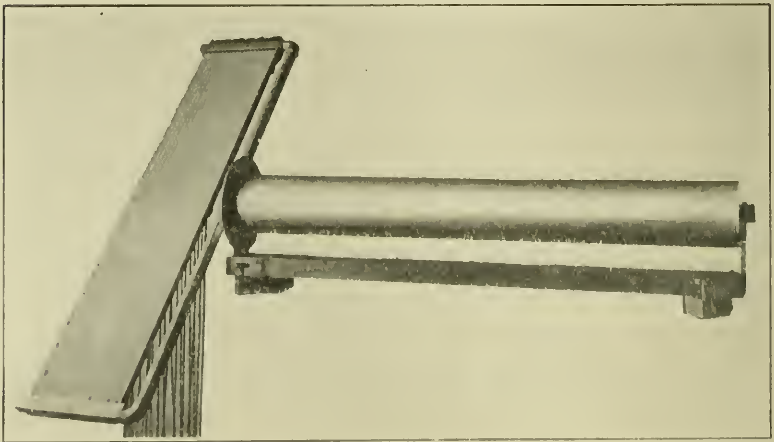
* Communicated by the Author.

FIG. 1.



Multiple tube manometer, upright.

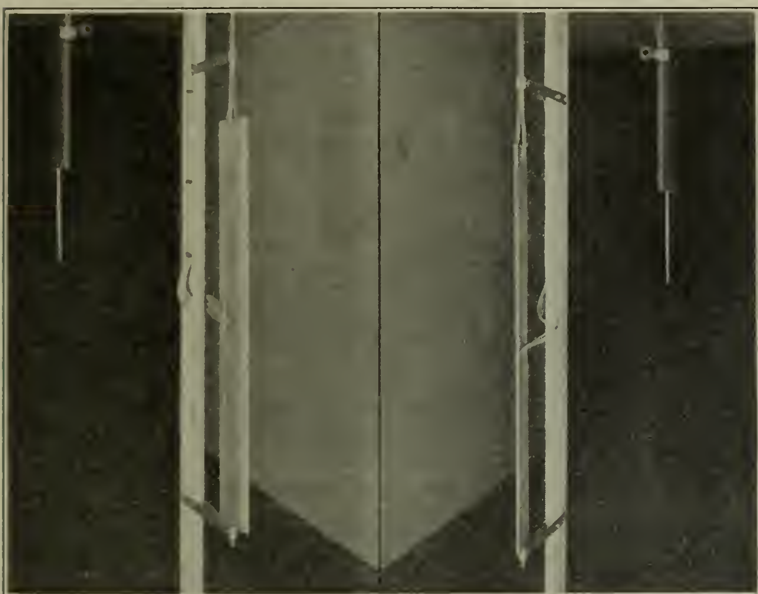
FIG. 2.



Multiple tube manometer, inclined (by rotation on a 2" pipe running endwise through the tank and resting in end bearings).

*Degree of Accuracy.*—The individual tubes are calibrated with a hook gauge truly to $^1/_{1000}$ inch water head referred to the zero position of the meniscus. When so many tubes are used that the surface of the alcohol in the cistern sinks appreciably, the amount of this fall is noted on an open-ended tube and applied as a correction. This never is large. For the surface area of the fluid in the tank is ten thousand times the projected area of one

Fig. 3.



Nipple and tube connection between aerofoil and manometer.

meniscus. Hence, when one tube only is used, the error due to neglecting the fall in the tank is .01 per cent., if the tube be vertical; .05 per cent., if sloped 1 in 5; and .10 per cent., if sloped 1 in 10. If ten tubes are used at once, all under pressure or all under suction, the error is ten times as much, and may require correction, as above indicated.

*Application.*—Figs. 2 and 3 illustrate the manner of connecting the multiple-tube manometer to an aerofoil whose pressure distribution is to be studied at various wind speeds and incidences. From the manometer nipple ⅛-inch rubber tubing is conducted

down the back of the tube-holder; thence through the floor of the room and the ceiling of the wind tunnel; thence down a stream-line strut to brass reduction couples, from the other ends of which fine spectacle tubes run to still finer nipples inserted in the aerodynamic model, to collect the pressure at a series of neighboring points. Due care is taken to locate the fine collector tubes in such manner as not to disturb the air flow over the portion of the surface under study.

In the apparatus here illustrated the brass nipples are of 0.025-inch bore and ½ inch long; the spectacle tubes are of $^1/_{32}$-inch bore and average nearly a foot long; and the whole tube system dampens the play of the alcohol columns sufficiently for convenient reading. Ten readings at a time may be taken for ten successive angles of incidence, and all completed within an hour, if the aerofoil be rotated from without, while the wind speed remains unchanged.

Except at the trailing edge of the aerofoil, each brass nipple collects the same pressure when the other nine are present as when they are absent. In an actual experiment each of the two rearmost nipples collected pressures which were false by 0.01 inch to 0.02 inch of water when the other nine were present. This error in the two rearmost pressures may entail an error of about 1 per cent. in the resultant pressue for the entire surface.

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**The Action of Carbonic Acid on Sulphides.** (*Scientific Proceedings Royal Dublin Society,* vol. xv, p. 171, 1917.)—E. A. Letts and Florence W. Rea, in the course of a study of the chemistry of foul mud deposits, made some studies of the actions of solutions of carbonic acid on sulphides, the results of which are interesting to analytical chemists and geologists. It has long been believed that sulphates may be reduced by the action of organic matter to sulphides, and this, according to Beyerink and Van Delden, takes place under the influence of specific microbes: *Microspira desulphuricans* in fresh water, and *M. estuarii* in salt water. Letts and Rea found that a current of carbonic acid passed into a solution of sodium sulphide produces a rapid evolution of hydrogen sulphide, the whole of the sodium salt being ultimately converted into sodium acid sulphate. Calcium sulphide is decomposed to nearly fifty per cent., the soluble, so-called bicarbonate, being formed. Freshly precipitated ferrous sulphide is slowly decomposed by carbonic acid, the final result being the soluble ferrous "bicarbonate." H. L.

# FACTORS OF CLIMATIC CONTROL.[1]

BY

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## Chapter I.

### GENERAL SUMMARY.

#### INTRODUCTION.

The following is a discussion of the principal factors, and the effects of their possible changes, that determine what the climate —the various averages and extremes of weather—of any given place shall be; a discussion of the physics of climate and not of its geographic distribution.

Many people, relying on their memories alone, insist that our climates are now very different from what they used to be. Their fathers made similar statements about the climates of still earlier times, as did also their fathers' fathers, as their several writings show, and so on through the ages; and the bulk of this testimony is to the effect that our climates are getting worse—evidence, perhaps, that flesh has always been heir to ills. The records, however, of the past 100 years show that while there have been several slight and short-period (2 to 3 or 4 years) climatic changes during that time, that will be explained later, there have been no long-period ones. There is, though, much evidence that appreciable climatic changes of many years' duration have occurred within historic times. This evidence, which many do not accept as conclusive, is found in the growth rings of old trees; the known changes in the areas and depths of several inland seas; the records in regard to the breaking up of ice in rivers and the opening of navigation; and in a variety of other more or less significant facts.

But whatever the truth in regard to historic climates may be, nothing is more certain than that during the geologic past there have been many and important climatic changes of great duration. Innumerable fossil remains both in the Arctic and Antarctic regions tell of long ages when genial or, at least, temperate cli-

[1] Continued from p. 674, Vol. 188, November, 1919.

mates extended well among the higher latitudes, while deep-scorings and ancient moraines, hundreds and even thousands of miles from the nearest existing glacier, tell quite as positively of other ages when vast ice sheets spread far into the zones we now call temperate; and this in spite of the fact (there is no good evidence to the contrary) that from the beginning of geologic records the earth has been divided into climatic zones arranged substantially as at present—warmest in equatorial regions and coldest about the poles.

It must be remembered, of course, that the previous existence of comparatively mild climates in limited high latitude regions does not prove that the average temperature of the world as a whole was then much if any higher than it is now, but only that at those places the growing seasons were long enough to permit the then indigenous vegetation to mature its seeds (a much more rapid process in high latitudes owing to the greater length of the summer days than in low), and that the temperature of the littoral waters at these same places was such as to foster the local marine life. Both conditions conceivably might have been met by a free and therefore abundant oceanic circulation; or, perhaps, locally by protection from cold currents and drifting ice. Similarly, local glaciation doubtless often was produced by local causes. But, on the other hand, such extensive glaciation as several times obtained must have required a world-wide lowering of temperature. Indeed, no escape seems possible from the conclusion that the world has experienced many a profound climatic change of both types, local and universal.

When this series of climatic changes began there is no sure means of knowing, for the records, especially those of glacial origin, grow gradually fainter and more scanty with increase of geologic age, so scanty indeed as to force the belief that the effects of many of the earlier changes may long since have been completely obliterated. But, however this may be, it is well-nigh certain that from the time of the earliest known of these changes down to the very present the series has been irregularly continuous, and the end, one might reasonably assume, is not yet. Change after change of climate in an almost endless succession, and even

additional ice ages, may still be experienced, though when they shall begin (except in the case of the small and fleeting changes to be noted below), how intense they may be, or how long they shall last, no one can form the slightest idea.

Clearly, then, a matter so fundamental as this, namely, the profound modification of those agencies that not only fashion the face of the earth, but also control its flora and govern its fauna, challenges and deserves every contribution that science can give to its complete or even partial elucidation. Hence it is that during the past fifty years, or more, numerous attempts, some of them invoking purely terrestrial and others extra-terrestrial or cosmical conditions, have been made to find a probable and at the same time an adequate physical basis for, or cause of, the known climatic changes of the distant past, and especially for those disastrous changes that brought about the extensive glaciations that prevailed during the so-called ice ages. But nearly all the older suggestions and working hypotheses as to the cause of the ice ages have been definitely and finally abandoned, either because of inconsistency with known physical laws, or abandoned because they were found inadequate to meet the conditions imposed upon them by the results of the very investigations which, in many cases, they themselves had helped to inspire.

### FACTS OF CLIMATIC CHANGES.

Among the more important facts with respect to climatic changes that appear to have been established and which presumably, therefore, must be met by any theory that would account for such changes, or explain specifically the origin of ice ages, are the following:

(*a*) The number of larger climatic changes were at least several, the smaller many.

(*b*) The greater changes and doubtless many of the smaller also were simultaneous over the entire earth (there is accumulating evidence in favor of this conclusion), and in the same sense; that is, the world became colder everywhere at the same time (climatically speaking) or warmer everywhere.

(*c*) They were of unequal intensity.

(*d*) They were of irregular occurrence and of unequal duration.

(*e*) They, at least one or more, progressed with secondary variations of intensity, or with advances and retreats of the ice front.

(*f*) There often were centres of maximum intensity—certainly of ice accumulation and, doubtless, of other effects.

(*g*) There were numerous local changes, suggestive of local causes.

(*h*) They have occurred from early, probably from the earliest, geological ages down to the present, and presumably will continue irregularly to recur for many ages yet to come.

## EXISTING FACTORS OF CLIMATIC CONTROL.

Before attempting to find the probable cause or causes of climatic changes it will be convenient first to consider the present factors of climatic control, since the variations of some of these undoubtedly have produced such changes, even, presumably, some if not all of those great changes that brought on maxima and minima of glaciation. It is possible, of course, that neither singly nor collectively were the factors in question largely productive of the known changes in geologic climates, but as climate to-day is subject to a complex control, all terms of which are more or less variable, it is certain that the climates of that portion of the geologic past (the only portion that will here be considered) during which the earth had an atmosphere and a hydrosphere, were also subject to a similar complex control consisting certainly of all the factors that now are effective, and probably of no others. Hence, while it is conceivable that some one dominant cause such as marked and age-long changes in the solar constant, the passage of the solar system through a vast nebula, and the like, may have produced all the great changes of geologic climates, it seems far safer to assume that climate was then controlled essentially as climate is now controlled, and, therefore, that the climatic changes of the past, whatever their nature, intensity, or duration, were due to changes in those factors of climatic control which are now operative and known to be appreciably variable.

The following list includes the principal factors of climatic control as they exist to-day:

*Chief Factors of Climatic Control.*

| Name | Character |
| --- | --- |
| 1. LATITUDE. | Invariable to within negligible amounts. |
| 2. BRIGHTNESS OF MOON AND PLANETS. | Widely variable, but of no climatic significance, since they jointly produce a temperature variation of only 0.0001° C., roughly. |
| 3. SOLAR "CONSTANT" AT A FIXED DISTANCE. | Slightly variable. There are small irregular variations of, roughly, a seven to ten day period and probably also a small variation coincident with the eleven year sun spot period. Other changes are not known, but may exist. |
| 4. SOLAR DISTANCE. | Slightly variable, with a geologically negligible annual period due to eccentricity of the earth's orbit; and also, for the same reason, both a 100,000 year, roughly (now about 80,000 year), secular period; and a much larger pseudo period. The longer of these eccentricity changes undoubtedly are of climatic importance, but, as presently explained in the discussion of Croll's theory, there is strong evidence against the assumption that they were the chief or even an important factor in the production of glaciation. There also are slight monthly changes in the solar distance due to perturbations by the moon; and other slight changes owing to perturbations by the planets. In any case, however, the climatic effect due to perturbations is negligible—a maximum temperature change (computed) of, roughly, 0.01° C. |
| 5. OBLIQUITY OF ECLIPTIC. | Slightly variable. According to Sir John Herschel this variation never exceeds 1° 20′ on either side of the mean; and according to Newcomb, while the limit of variation is still unknown, the amount does not exceed 2° or 3° in a million years. In either case recent geologic climates, including that of the last ice age, could not have been much influenced by this factor. |
| 6. PERIHELION PHASE. | Variable through a period of, roughly, 21,000 years. By virtue of this variation the winter of the southern hemisphere, say, may at one time occur, as it now does, at aphelion, and therefore be long and cold; and again at perihelion, when it must be relatively short and mild. However, while this is a climatic factor which varies with the eccentricity of the earth's |

*Chief Factors of Climatic Control.*—Continued.

| Name | Character |
|---|---|
| | orbit, the period is too short to permit of its being considered as of great influence in the production of either the glacial or interglacial climates. |
| 7. EXTENT AND COMPOSITION OF THE ATMOSPHERE. | Probably somewhat variable through geological periods, otherwise relatively fixed. |
| 8. VULCANISM. | Irregularly variable. |
| 9. SUN SPOTS. | Greatly variable, with an 11-year period and probably other periods also, both longer and shorter. |
| 10. LAND ELEVATION. | Greatly variable through geological periods, otherwise relatively fixed. |
| 11. LAND AND WATER DISTRIBUTION. | Greatly variable through geological periods, otherwise relatively fixed. |
| 12. ATMOSPHERIC CIRCULATION. | Largely dependent upon the distribution of land and water, upon land elevation and upon oceanic circulation, and therefore, in many regions radically variable through geological periods. |
| 13. OCEAN CIRCULATION. | Greatly variable through geological periods, otherwise relatively fixed. |
| 14. SURFACE COVERING. | Greatly variable, in many places, from season to season; and also irregularly so from age to age. |

Since these are the factors that now control climate, it seems probable, as already stated, that even those profound climatic changes with which the geologist is concerned were also caused by variations in one or more of these same factors. Indeed, certain of these factors—vulcanism, land elevation, and oceanic circulation—are known to have varied greatly during the several geologic periods, while the extent and composition of the atmosphere are suspected also to have changed. It will be well, therefore, to consider what effects such variations probably could have—in some cases surely have had—on our climates. This will constitute the first step in the problem of geologic climates. The next step must be taken by the geologist himself, for he must say whether the climatic changes possible through the supposed causes would be sufficient to account for the observed results, and especially whether the known climatic changes and the known variations in

the factors here considered occurred at such times and places as to permit of the assumption that they were actually related in the sense of cause and effect.

These several factors will be considered in the same order as above listed.

1. Since the wandering of the pole is limited to only a few metres, it is obvious that the resulting changes in the latitude produce no appreciable climatic effects.

2. The brightness of the moon, and also that of each of the several planets, is known in terms of that of the sun. On the assumption that the heat they supply is in proportion to their light it appears that at most their variations in phase and distance can alter the temperature of the surface of the earth by no more than 0.0001° C., an amount that obviously is wholly negligible.

## CHAPTER II.

### PRINCIPAL ICE-AGE THEORIES.

#### FACTORS 3, 4, 5, 6, 7.

IT would be easy to catalogue perhaps a score of more or less rational hypotheses in regard to the origin of the ice ages, the subject under which the greater climatic changes generally are discussed, and doubtless even a larger number that are quite too absurd ever to have received serious consideration, and to point out in each case the known and the suspected elements of weakness. But this would only be a repetition of what, in part at least, has often been done before and, therefore, could serve no good purpose.

As already stated, only a few of these hypotheses still survive, nor do all of even these few really merit the following they have. Indeed, the only ones which still claim a large number of adherents are, respectively:

3. (*a*) *The Solar Variation Theory.*—This is based on the assumption that the solar radiation (the only solar influence that by any known process can affect terrestrial temperatures and terrestrial climates) has waxed and waned, either cyclically or irregularly, through considerable ranges and over long intervals of time.

This theory is seductively attractive—it looks so simple, so

sufficient, and so safe from attack. There are, however, two criticisms of it that should be mentioned: (1) A change of the solar constant obviously alters all surface temperatures by a roughly constant percentage. Hence a decrease of the heat from the sun would, in general, cause a decrease of the interzonal temperature gradients; and this in turn a less vigorous atmospheric circulation, and a less copious rain or snowfall—exactly the reverse of the condition, namely, abundant precipitation, most favorable to extensive glaciation. (2) If the solar variation theory is true it follows, as will be shown later, that great solar changes and extensive mountain building must usually, if not always, have been coepochal—a seemingly complete *reductio ad absurdum.*

4, 5, 6. (*b*) *Croll's Eccentricity Theory.*[2]—To make this theory clear, it is necessary to recall two important facts in regard to the earth's movement about the sun: (1) That the orbital position of the earth at any season, that of midsummer, say, progressively changes at such rate as to describe a complete circuit in about 21,000 years. This necessarily produces a cyclic change of the same period in the length, temperature and contrast of the seasons, and also in the contrast between the climates of the two hemispheres, northern and southern. Thus, when aphelion is attained near midsummer of either hemisphere as it now is for the northern, that part of the earth enjoys comparatively long, temperate summers, and short, mild winters; while the opposite hemisphere, the southern at present, is exposed to short hot summers, and long, cold winters. Hence, on such occasions, the climatic contrast between the two hemispheres is at a maximum, provided, of course, that their ratios of land to water areas and other factors are the same. After about 10,500 years another maximum contrast occurs, but with the climates of the two hemispheres interchanged, and so on indefinitely. (2) That the eccentricity of the earth's orbit, never greater than 0.07, and at rare intervals dropping to nearly or even quite zero, undergoes irregular but always slow and long cyclic changes. In addition to a change usually, though not always, relatively small whose average period is roughly 100,000 years (now about 80,000), the eccentricity has also a far more irregular and generally much larger change whose average period, if a thing so irregular may be said to have

[2] *Phil. Mag.*, 28, p. 121, 1864, and elsewhere.

a period, is three or four times as great. That is, as a rule, the eccentricity of the earth's orbit is continuously large, within the limit 0.07, or continuously small, for a period of 200,000 years, more or less; but in each case unequally so, because of the shorter period and more regular changes.

The first of these phenomena, the continuous change of the perihelion phase, varies, as explained, the relative lengths and intensities of the summers and winters of the northern and southern hemispheres; while the second, or the change of eccentricity of the earth's orbit, varies the magnitudes of these contrasts.

Now Croll's theory of the ice ages assumes that when the earth's orbit is very eccentric, or when the earth's maximum solar distance differs largely from its minimum solar distance, ice will accumulate to a great extent over that half of the globe which has its winter during aphelion.

For some time this theory was very generally accepted, and it seems still to have many adherents, despite the destructive criticisms of Newcomb[3] and Culverwell.[4]

The chief objections to Croll's theory are:

1. That the assumption that midwinter and midsummer temperatures are directly proportional to the sun's heat at these times is not at all in accord with observed facts.

2. That each ice-age (within a glacial epoch, when eccentricity is large) would be limited to a fraction of the secular perihelion period, 21,000 years, which, according to most geologists, is too short a time.

3. That the successive ice ages would have occurred alternately in the northern and southern hemispheres instead of, as is generally believed to have been the case, in both hemispheres simultaneously.

4. That during the past 3,000,000 years there would have been fully 100 extensive glacial advances and retreats in each hemisphere (eccentricity having been rather large through much the greater portion of this time), a deduction unsupported by confirmatory geological evidence.

5. That the last extensive ice sheet in either hemisphere must have retracted roughly to its present limits some 80,000 years ago (eccentricity having become small about that time and remained

[3] *Amer. Jr. Sci.*, 11, p. 263, 1876; *Phil. Mag.*, 17, p. 142, 1884.

[4] *Phil. Mag.*, 38, p. 541, 1894.

small ever since) instead of less than 9000 as Gerald de Geer [5] has well-nigh conclusively demonstrated.

As W. B. Wright [6] puts it: "An almost fatal objection to Croll's famous theory is the date it assigns to the end of the last Ice Age, which it places at some 80,000 years back. If, as De Geer seems to have clearly established, the ice-margin retreated north past Stockholm only about 9000 years ago, this practically excludes any possibility of a connection between glaciation and changes in the eccentricity of the earth's orbit."

That changes in the maximum and minimum distances of the earth from the sun have affected our climates and that they will continue to affect them seem too obvious to admit of doubt, but that such changes ever were, or ever will be, of sufficient magnitude to be the sole, or even the chief, cause of an ice-age appears to be flatly contradicted both by rigid deductions from the laws of physics and meteorology and by close observations of geological records.

7. (*c*) *The Carbon Dioxide Theory.*—This theory, advocated by Tyndall,[7] Arrhenius,[8] Chamberlain [9] and others, is based on the selective absorption of carbon dioxide for radiation of different wave lengths, and on its assumed variation in amount.

It is true that carbon dioxide is more absorptive of terrestrial than of solar radiations, and that it therefore produces a greenhouse or blanketing effect, and it is also probably true that its amount in the atmosphere has varied through appreciable ranges, as a result of volcanic and other additions on the one hand, and of oceanic absorption and chemical combination on the other. But it is not possible to say exactly how great an effect a given change in the amount of carbon dioxide in the atmosphere would have on the temperature of the earth. However, by bringing a number of known facts to bear on the subject it seems feasible to determine its approximate value. Thus the experiments of Schlaefer [10] show that, at atmospheric pressure, a column of carbon dioxide 50 centimetres long is ample for maximum absorption, since one of this length absorbs quite as completely as does

[5] *Geolog. Congress*, Stockholm, 1910.

[6] *The Quarternary Ice Age*, p. 451, Macmillan and Co., 1914.

[7] *Phil. Mag.*, 22, p. 277, 1861.

[8] *Phil. Mag.*, 41, p. 237, 1896.

[9] *Jr. Geol.*, 7, p. 545, 1899.

[10] *Ann. der Phys.*, vol. xvi, p. 93, 1905.

a column 200 centimetres long at the same density. Also the experiments of Angström,[11] and those of E. v. Bahr,[12] show that the absorption of radiation by carbon dioxide or other gas increases with increase of pressure, and, what is of great importance, that both qualitatively and quantitatively this increase of absorption is exactly the same whether the given higher pressure, be obtained by compression of the pure gas to a column of shorter length, or, leaving the column unchanged, by the simple addition of an inert gas.

According to these experiments, if a given column or quantity of carbon dioxide at a pressure of 50 mm. absorbs 20 per cent. of the incident selective radiation, then, at 100 mm. it will absorb 25 per cent., at 200 mm. 30 per cent., at 400 mm. 35 per cent., and at 800 mm. about 38.5 per cent.

Now, the amount of carbon dioxide in the atmosphere is equivalent to a column of the pure gas, at ordinary room temperature and atmospheric pressure, of roughly 250 centimetres in length. Hence, as a little calculation proves, using the coefficients of absorption at different pressures given by the experiments of Angström and E. v. Bahr, just described, the carbon dioxide now in the atmosphere must, under its present vertical distribution, absorb radiation very approximately as would a column 475 centimetres long of the pure gas at the barometric pressure of 400 millimetres. But Schlaefer's experiments above referred to show that such a column would be just as effective an absorber as a cylinder two or three times this length, and, on the other hand, no more effective than a column one-half or one-fourth as long; in each case the absorption would be complete in the selective regions of the gas in question.

Hence, finally, doubling or halving the amount of carbon dioxide now in the atmosphere, since this would make but little difference in the pressure, would not appreciably affect the total amount of radiation actually absorbed by it, whether of terrestrial or of solar origin, though it would affect the vertical distribution or location of the absorption.

Again, as explained by Abbot and Fowle,[13] the water vapor

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[11] *Arkiv för Matematik, Astron. och Fysik,* vol. iv, No. 30, 1908.

[12] *Ann. der Phys.,* vol. xxix, p. 780, 1909.

[13] *Annals of the Astrophysical Observatory,* Smithsonian Institution, vol. ii, p. 172, 1908.

always present in the atmosphere, because of its high coefficients of absorption in substantially the same regions where carbon dioxide is effective, leaves but little radiation for the latter to take up. Hence, for this reason, as well as for the one given above, either doubling or halving the present amount of carbon dioxide could alter but little the total amount of radiation actually absorbed by the atmosphere, and, therefore, seemingly, could not appreciably change the average temperature of the earth, or be at all effective in the production of marked climatic changes.

Nevertheless, in spite of the above objections, there appears to be at least one way (variation in absorption at levels above the water vapor) by which a change, especially if a decrease, in the amount of carbon dioxide in the atmosphere might affect temperatures at the surface of the earth. Hence, the above arguments do not perhaps fully warrant the idea that no such change was ever an appreciable factor in the production of an ice age.

Further consideration of this particular point will be taken up later, after the discussion of certain other questions essential to a clear understanding of the subject.

These three theories, then, of the origin of the ice ages, namely: The solar variation theory, the eccentricity theory, and the carbon dioxide theory, are the only ones that at present appear to have many adherents, and even these few seem more likely to lose than to gain in number and ardency of defenders. The first is strong only as, and to the extent that, other theories are disproved or shown to be improbable; the second has failed utterly under searching criticism; while the third has been sadly impaired.

## Chapter III.

### 8. VULCANISM: THEORY.

*(The mathematical portions of this chapter, provided their conclusions are accepted, may be omitted in reading without serious loss of continuity.)*

#### GASEOUS CONTRIBUTION TO THE ATMOSPHERE.

Although a variety of gases, vapors and fumes are given off by active volcanoes, probably only one of them, carbon dioxide, is of sufficient volume and of such nature as to produce any effect on climate. Indeed, besides carbon dioxide, the only atmospheric constituents that are especially effective in modifying

the average temperature of the earth are water vapor and, probably, ozone. The former of these, or water vapor, except as locally modified by temperature and topography, including location and extent of land and sea, presumably has varied but little in amount since the formation of the earliest oceans, while a practically continuous series of animal fossils from beyond the earliest paleozoic age to the present is abundant proof of an equally continuous supply of free oxygen. Hence, in an effort roughly to determine what climatic changes might have been caused by variations in the atmosphere, whether produced by vulcanism or otherwise, it would appear that only the amount of carbon dioxide need be considered.

But this has been discussed above, to some extent, and will be taken up again in its proper order. Suffice it to anticipate here the general conclusion that while variations in the amounts of carbon dioxide in the atmosphere may have somewhat modified our climates, it probably never was the controlling or even an important factor in the production of any one of the great climatic changes of the past, nor can be of any great climatic change the future possibly may bring.

### CHANGE IN SURFACE COVERING.

The effect of volcanic ejecta, whether in the nature of ash, or lava flow, is to convert the region so covered into a temporary desert, even where rain may be abundant, and, therefore, to subject it to an increased range of temperature extremes, and at the same time, if in a previously vegetated region, slightly to increase its average temperature, owing to decrease of evaporation. However, it seems highly probable that the areas so deprived of vegetation were never at any one time sufficiently large to produce marked effects upon the climate of the world as a whole, nor indeed anywhere except over themselves and within their own immediate neighborhoods. Hence, in considering universal climatic changes, it seems safe to neglect this special effect of volcanic activity.

### DUST IN THE UPPER ATMOSPHERE.

It was suggested a number of years ago by the cousins P. and F. Sarasin [14] that the low temperature essential to the glaciation

[14] *Verhandlungen der Naturforschenden Gesellschaft in Basel,* vol. xiii, p. 603, 1901.

of ice ages was caused by the absorption of solar radiation by high volcanic dust-clouds. But the idea that dust of this nature, when scattered through the atmosphere, may lower the temperature of the surface of the earth was already old, having been advanced at a much earlier date, in fact, long before even the existence of ice ages had been suspected, much less attempts made to find their cause. Thus, in May, 1784, Benjamin Franklin (and he may not have been the first) wrote as follows:

> During several of the summer months of the year 1783, when the effects of the sun's rays to heat the earth in these northern regions should have been the greatest, there existed a constant fog over all Europe, and great part of North America. This fog was of a permanent nature; it was dry, and the rays of the sun seemed to have little effect toward dissipating it, as they easily do a moist fog arising from the water. They were indeed rendered so faint in passing through it that, when collected in the focus of a burning-glass, they would scarce kindle brown paper. Of course, their summer effect in heating the earth was exceedingly diminished.
>
> Hence the surface was early frozen.
>
> Hence the first snows remained on it unmelted, and received continual additions.
>
> Hence perhaps the winter of 1783-4 was more severe than any that happened for many years.
>
> The cause of this universal fog is not yet ascertained. Whether it was adventitious to this earth, and merely a smoke proceeding from the consumption by fire of some of those great burning balls or globes which we happen to meet with in our course round the sun, and which are sometimes seen to kindle and be destroyed in passing our atmosphere, and whose smoke might be attracted and retained by our earth; or whether it was the vast quantity of smoke, long continuing to issue during the summer from Hecla, in Iceland, and that other volcano which arose out of the sea near that island, which smoke might be spread by various winds over the northern part of the world, is yet uncertain.
>
> It seems, however, worthy the inquiry, whether other hard winters, recorded in history, were preceded by similar permanent and widely-extended summer fogs. Because, if found to be so, men might from such fogs conjecture the probability of a succeeding hard winter, and of the damage to be expected by the breaking up of frozen rivers in the spring; and take such measures as are possible and practicable to secure themselves and effects from the mischiefs that attend the last.[16]

The idea, then, that volcanic dust may be an important factor in the production of climatic changes is not new, though by what physical process it could produce this result apparently has not

[16] See Sparks's "Life of Benjamin Franklin," vol. vi, 455–457 (cited in *Proceedings of the Amer. Phil. Soc.*, vol. xlv, p. 127, 1906.)

formerly been explained, nor has the idea previously been specifically supported by a long series of direct observations. This is not to be taken as a criticism of the above-mentioned pioneer paper by the Sarasin cousins, for indeed the arguments, now easy, necessary to show that it must be a factor, were at that time impossible, because the observations upon which these arguments largely are based had not then been made. In fact, the absorption of radiation by volcanic dust, by which they supposed the earth's temperature to be lowered, can now be shown to be, of itself alone, not only insufficient, but even productive, in all probability, of the opposite effect—of a warming instead of a cooling of the earth's surface.

To make this point clear: Consider a thin shell of dust about the earth and let $I$ be the average intensity of the normal component of solar radiation on it, and $I_e$ the intensity of the radiation reaching the earth. Further, let $a$ be the average coefficient of absorption of the dust shell for solar radiation, a coefficient independent, presumably, of intensity, and $b$ its coefficient of absorption for terrestrial radiation, also independent of intensity. Obviously, in the case of equilibrium, all the energy absorbed by the dust is radiated away; half of it, very approximately, to the earth and half of it to space. Hence, starting with $I$ as the intensity of the solar radiation normally incident per unit area and unit time, upon the dust layer, we have,

$$I_e = I \left\{ 1 + k\,(b - a) \right\} \text{ - - - - - - - - - - - } (A.)$$

in which

$$k = \tfrac{1}{2} \left\{ 1 + \frac{b}{2} + \left(\frac{b}{2}\right)^2 + \cdots\cdots + \left(\frac{b}{2}\right)^\infty \right\}.$$

Now $b$ is positive, and, therefore, $k$ is also positive. Hence

$$I \left\{ 1 + k\,(b - a) \right\} \gtreqless I, \text{ according as } b \gtreqless a.$$

The conclusion, therefore, is: *The total amount of radiation reaching the earth is increased, unchanged, or decreased owing to absorption by the surrounding dust layer according as the dust's coefficient of absorption of terrestrial radiation is greater than, equal to, or less than its coefficient of absorption of solar radiation.*

Actually nearly all, both of the incoming and of the outgoing radiation, is oblique, but as equal portions of each pass through

equal thickness of the shell it follows that the conclusion reached for normal radiation applies also for the oblique radiation.

While this general conclusion is self-evident, and, therefore, might have been stated without the use of symbols, nevertheless equation ($A$), to be used later on, will be found convenient in attempts to obtain quantitative values.

Now in the case of many, if not all, rocky materials, such as make up the particles of volcanic dust, the coefficient of absorption is much greater for terrestrial radiation than for solar radiation,[16] or, in terms of the above symbols, in the case of volcanic dust, $b$ is greater than $a$. Hence, so far as mere *absorption* of radiation is concerned, the only action mentioned by the cousins Sarasin, a veil of volcanic dust, in all probability, would slightly increase and not, as they supposed, decrease the average temperature of the earth.

But, then, absorption is not the only effect of a dust veil on radiation; *reflection* and *scattering* both are important and must be fully considered.

These actions, however, reflection and scattering, depend fundamentally upon the ratio of the linear dimensions of the particles concerned to the wave length of the incident radiation, and, therefore, before undertaking to discuss them in this connection, it will be essential to determine the approximate size of the individual grains of floating volcanic dust, and also the average wave lengths in the regions of the respective maximum intensities of solar and terrestrial radiation. It will be desirable, also to consider whether or not, and, if so, how, dust of any kind can remain long suspended in the atmosphere. And this point, involving the structure of the atmosphere, will be examined first, since, obviously, the longer the dust can float the more important, climatically, it may have been in the past and in the future may again become.

*Physical Structure of the Atmosphere.*—The atmosphere is divisible into the stratosphere and the troposphere; or the isothermal region and the convective region; or, in other words, that region, in middle latitudes at and beyond about 11 kilometres above sea level, where, because of freedom from vertical convection, ordinary clouds never form, and that other, or turbulent,

[16] Coblentz, Publications of Carnegie Institution of Washington, Nos. 65 and 97.

stormy region below this level, which is frequently swept by clouds and washed by snow and rain. The physical reason for or cause of the existence of the isothermal region is well known (see Chapter III, Part I) and is such that it is certain that ever since the earth was warmed by solar radiation, as at present, rather than by internal heat, the temperature of its atmosphere beyond a certain level, whatever its composition, must have varied but little, as it now varies but little, with change of altitude, and therefore that this region must then have been free, as it now is free, from clouds and condensation. Obviously, then, this peculiar physical structure of the atmosphere is of great importance in determining the duration of dust suspension for, clearly, any volcanic or other dust, that by whatever process is gotten into and distributed through the isothermal region where there are no clouds or other condensation to wash it out, must drift about until gravity, overcoming the viscosity of the atmosphere, by slow degrees shall have pulled it down to the region of clouds and storms, where it becomes moisture laden and quickly brought to the earth. How long such process must take depends, of course, upon a number of things, among which the size of the particles is vitally important.

*Size of Volcanic Dust Particles.*—For two or three years after the eruption of Krakatoa, in 1883, also after the eruption of Mont Pelé and Santâ Maria, in 1902, and again after the eruption of Katmai, in 1912, a sort of reddish-brown corona was often, under favorable conditions, observed around the sun. It was from 10 to 12 degrees wide, and had, to the outer edge, an angular radius of from 22 to 23 degrees. This phenomenon, known as Bishop's ring, clearly was a result of diffraction of sunlight by the particles of volcanic dust in the upper atmosphere, and therefore it furnished a satisfactory means for determining the approximate size of the particles themselves. The subject has been rather fully discussed by Pernter,[17] who finds the diameter of the particles, assuming them spherical, to be approximately $185 \times 10^{-6}$ cm., or 1.85 microns. The equation used has the form

$$r = \frac{m}{\pi} \frac{\lambda}{\sin \theta}$$

in which $r$ is the radius of the dust particle, $\lambda$ the wave length of

[17] *Met. Zeit.*, 6, p. 401, 1889.

the diffracted light (here taken as $571 \times 10^{-7}$ cm., or 0.571 micron), $\theta$ the angular radius of the ring, and $m$ a numerical term which for the outer edge of the ring, and successive minima of brightness, has the approximate values,

$$\frac{\pi}{2}(n + 0.22)$$

in which $n = 1, 2, 3, \ldots$, respectively.

Now, since the width and angular dimensions of Bishop's ring, as seen at different times and different places, have varied but little, the above value, 1.85 microns, may provisionally be assumed to be the average diameter of those particles of volcanic dust that remain long suspended in the atmosphere.

*Time of Fall.*—The steady or terminal velocity of a sphere falling in a fluid, assuming no slip between fluid and sphere, is given by Stokes's [18] equation,

$$V = \frac{2}{9} g r^2 \left( \frac{\sigma - \rho}{\mu} \right)$$

in which $V$ is the velocity of the fall, $g$ the acceleration of gravity, $r$ the radius of the sphere, $\sigma$ the density of the sphere, $\rho$ the density of the fluid, and $\mu$ its viscosity.

However, there always is slip, so that the actual velocity of fall is, according to Cunningham,[19]

$$V = \frac{2}{9} g r^2 \left( \frac{\sigma - \rho}{\mu} \right) \left( 1 + A \frac{l}{r} \right)$$

in which $l$ is the free path of the gas molecules, $A$ a constant, and the other symbols as above explained.

Obviously, $l$, other things being equal, is inversely proportional to the gas density, or pressure, if temperature is constant, and directly proportional to the absolute temperature if the pressure is constant. Hence,

$$V = \frac{2}{9} g r^2 \left( \frac{\sigma - \rho}{\mu} \right) \left( 1 + \frac{B}{rp} \right) \text{ - - - - - - - - - - - } (1)$$

in which $B$ is a constant for any given temperature, $p$ the gas pressure, or, if preferred, barometric height.

Now, a series of valuable experiments by McKeehan [20] has

[18] *Math. and Phys. Papers*, vol. iii, p. 59.

[19] *Proc. Roy. Soc.*, 83 A, p. 357, 1910.

[20] *Phys. Rev.*, 33, p. 153, 1911.

shown that for 21° C., and when $p$ is the pressure in terms of millimetres of mercury,

$$B = .0075 \pm 3.$$

The value of $\mu$, for dry air, is also closely known from the work of a number of experimenters, all of whom obtained substantially the same results. From a careful review of the whole subject, Millikan[21] finds that at 23° C.,

$$\mu = 1824 \times 10^{-7}, \left( \text{more recently } 18226 \times 10^{-8} \right),$$

and that, for the temperature, $t$, Centigrade,

$$\mu_t = \frac{150\,38\,T^{\frac{3}{2}}}{T + 124} \times 10^{-7}, \text{ approximately,}$$

where $T = 273.11 + t$.

It is easy, therefore, to compute, by the aid of equation (1), the velocity of fall of volcanic dust, assuming gravity to be the only driving force. There is, of course, radiation pressure, both toward and from the earth, as well as slight convective and other disturbances, but presumably gravitation exerts the controlling influence.

The following table of approximate velocities and times of fall for volcanic dust was computed by substituting in equation (1) the given numerical values, namely:

$g = 981 \frac{\text{cm.}}{\text{sec.}}$
$r = .000092$ cm.
$\sigma = 2.3$ approximate density of Krakatoa dust.
$\rho = 0$, being negligible relative to $\sigma$.
$\mu = 1416 \times 10^{-7}$, appropriate to $-55°$ C., roughly the temperature of the isothermal region in middle latitudes.
$B = .0056$, appropriate to $-55°$ C.
$p$ = millimetres barometric pressure.

According to this table, it appears that spherical grains of sand of the size assumed, 1.85 microns in diameter, would require about one year to fall from only that elevation already reached by sounding balloons, 35.08 kilometres,[22] down to the under surface of the isothermal region, at the height of 11 kilometres.

[21] *Ann. der Phys.*, **41**, p. 759, 1913.
[22] *L'Astronomie*, 27, p. 329, 1913.

*Velocity and Time of Fall*

| Height in kilometres | Barometric pressure | Centimetres per second | Seconds per centimetre |
|---|---|---|---|
| 40 | 1.84 | 1.0215 | 0.979 |
| 30 | 8.63 | 0.2414 | 4.143 |
| 20 | 40.99 | 0.0745 | 13.427 |
| 15 | 89.66 | 0.0503 | 19.874 |
| 11* | 168.00 | 0.0408 | 24.492 |
| 0 | 760.00 | 0.0258† | 38.760† |

* Isothermal level of middle latitudes.
† Temperature 21° C.

As a matter of fact, volcanic dust, at least much of it, consists of thin-shelled bubbles or fine fragments of bubbles, and, therefore, must settle much slower than solid spheres, the kind above assumed. Indeed, the finest dust from Krakatoa, which reached a great altitude, probably not less than 40 nor more than 80 kilometres, was from two and a half to three years in reaching the earth, or, presumably, as above explained, the upper cloud levels.

At any rate, volcanic dust is so fine, and the upper atmosphere above 11 kilometres so free from moisture and vertical convection, that once such dust is thrown into this region, as it obviously was by the explosions of Skaptar Jökull and Asamayama in 1783, Babuyan in 1831, Krakatoa in 1883, Santâ Maria and Pelé in 1902, Katmai in 1912, and many others, it must require, as a rule, because of its slow descent, from one to three years to get back to the earth. And this clearly has always been the case since the earth first assumed substantially its present condition, or had a cool crust and a gaseous envelope.

Obviously, then, it is only necessary to determine the present action of such dust on incoming solar and outgoing terrestrial radiation in order to reach a logical deduction as to what its effect on climate must have been in the past if, through extensive volcanic activity, it ever more or less continuously filled the upper atmosphere for a long or even considerable term of years, as may have happened several times during the geologic ages. And the same conclusion in regard to the possible effect of dust on the climates of the past clearly applies with equal force to the climates of the future.

*Action of Dust on Solar Radiation.*—Since solar radiation at the point of maximum intensity has a wave-length less than

$5 \times 10^{-5}$ cm.,[23] or half a micron, and since fully three-fourths of the total solar energy belongs to spectral regions whose wave-lengths are less than $10^{-4}$ cm., or one micron, it follows that the cubes of solar wave-lengths must, on the whole, be regarded as small in comparison with the volume of a volcanic dust particle, the diameter of which, as above explained, is nearly 2 microns. Hence, in discussing the action of volcanic dust on incoming solar radiation, we can, with more or less justification, assume the particles to be opaque through reflection or otherwise, and, therefore, use Rayleigh's [24] arguments as applied to a similar case.

Let $r$ be the radius of the particle, $n$ the number of particles per cubic centimetre, and $a$ the projected joint area of these particles. Then, for random and sparsely scattered particles,

$$a = n\pi r^2$$

Hence, on dividing a plane parallel to the wave-front into Fresnel zones, it is seen that for each centimetre traversed the amplitude of the radiation is reduced in the ratio of 1 to $1 - n\pi r^2$. Therefore, if $A$ is the initial amplitude, and $A_x$ the amplitude after passing through $x$ centimetres of the uniformly dusty region, assuming $n\pi r^2$ to be only a small fraction of a square centimetre,

$$A_x = A\,(1-n\pi r^2)^x = Ae^{-n\pi r^2 x}$$

Further, if $I$ is the initial and $I_x$ the final intensity, then

$$I_x = Ie^{-2n\pi r^2 x}$$

Hence, in the case of volcanic dust, where, as already explained, $r = 92 \times 10^{-6}$ centimetre,

$$A_x = Ae^{-n\pi x\,(92)^2\,10^{-12}}$$

and

$$I_x = Ie^{-2n\pi x\,(92)^2\,10^{-12}}$$

Presumably, the particles of dust are not absolutely opaque and, therefore, $I_x$ probably is a little larger than the value here given, though even so this value is at least a first approximation.

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[23] Abbot and Fowle, *Annals Astrophys. Obsy.*, Smithsonian Inst., vol. ii, p. 104, 1908.

[24] *Phil. Mag.*, 47, p. 375, 1899.

*Action of Dust on Terrestrial Radiation.*—Terrestrial radiation, at the point of maximum intensity, has a wave-length of roughly, $12 \times 10^{-4}$ centimetres, and, therefore, the wave-lengths of nearly all outgoing radiation are large in comparison with the diameters of those volcanic dust particles that remain long suspended in the atmosphere. Hence, while such particles abundantly *reflect* solar radiation, as is obvious from the whiteness of the sky when filled by them, they can only *scatter* radiation from the earth, according to the laws first formulated by Rayleigh,[25] whose papers must be consulted by those who would fully understand the equations which here will be assumed and not derived.

Let $E$ be the intensity of terrestrial radiation as it enters the dusty shell, or as it enters the isothermal region, and $E_y$ its intensity after it has penetrated this region, supposed uniformly dusty, a distance $y$ centimetres; then, remembering that the dust particles are supposed to be spherical, according to Rayleigh,

$$E_y = Ee^{-hy}$$

where

$$h = 24\pi^3 n \frac{(K' - K)^2}{(K' + 2K)^2} \frac{T^2}{\lambda^4},$$

in which $n$ is the number of particles per cubic centimetre, $K$ the dielectric constant of the medium, $K'$ the dielectric constant of the material of the particles, $T$ the volume of a single particle, and $\lambda$ the wave-length of the radiation concerned.

But $K = 1$, and, since the dust seems generally to be a kind of glass, it may not be far wrong to assume that $K' = 7$. Hence, with these values,

$$h = 11\pi^3 n \frac{T^2}{\lambda^4}, \text{ nearly.}$$

*Relative Action of Dust on Solar and Terrestrial Radiation.*—To determine whether such a dust layer as the one under discussion will increase or decrease earth temperatures it is necessary to compare its action on short wave-length solar radiation with its action on long wave-length radiation from the earth.

In the case of solar radiation, as explained,

$$I_x = Ie^{-2n\pi x (92)^2 10^{-12}}$$

[25] *Loc. cit.*

Clearly, then, the intensity of the solar radiation is reduced in the ratio of 1 to $e$, or

$$I_x : I = 1 : e$$

when $x = \frac{10^{12}}{2n\pi(92)^4}$ centimetres $= \frac{188}{n}$ kilometres, approximately.

On the other hand, in the case of terrestrial radiation, where

$$E_y = Ee^{-11\pi^3 n \frac{T^2}{\lambda^4} y},$$

the intensity is reduced in the ratio of 1 : $e$, or

$$E_y : E = 1 : e,$$

when

$$y = \frac{\lambda^4}{11\pi^3 n T^2} \text{ centimetres,}$$

in which

$$T = \tfrac{4}{3}\pi(92)^3 10^{-18}$$

and

$$\lambda = 12 \times 10^{-4}, \text{ the region of maximum intensity.}$$

Hence,

$$y = \frac{5700}{n} \text{ kilometres, approximately.}$$

Therefore, finally,

$$y : x = 30 : 1, \text{ roughly,}$$

or the shell of volcanic dust, the particles all being the size given, is some thirty-fold more effective in shutting solar radiation out than it is in keeping terrestrial radiation in. In other words, the veil of dust produces an inverse greenhouse effect, and hence, if the dust veil were indefinitely maintained, the ultimate equilibrium temperature of the earth would be lower than it is when no such veil exists.

The ratio 30 to 1 in favor of terrestrial radiation in its ability to penetrate the dusty atmosphere may at first seem quite too large, but it should be remembered that the dust particles in question are to terrestrial radiation in general as air molecules are to solar radiation, in the sense that in both cases but little more than mere scattering takes place. Now it is obvious that the dust particles are many fold more effective in intercepting solar

radiation, which they appear to do chiefly by reflection, than is an equal mass of air molecules which simply scatter it; and hence it may well be that the above theoretically determined ratio, 30 to 1, is no larger than the ratio that actually exists, or, at any rate, that it is of the correct order.

It must be distinctly understood that certain of the assumptions upon which the foregoing is based—uniformity of size, complete opacity and sphericity of the dust particles, for instance—are only approximately correct, but they are the best that at present can be made, and doubtless give at least the order of magnitude of the effects, which, indeed, for the present purpose, is quite sufficient.

It may be well, in this connection, to call attention to the fact that the excessively fine dust particles, or particles whose diameters are half, or less, the wave-length of solar radiation (region of maximum intensity), and which, therefore, remain longest in suspension, shut out solar radiation many fold more effectively than they hold back terrestrial radiation. This is because both radiations, solar and terrestrial, are simply scattered by such small particles, and scattered in proportion to the inverse fourth power of the wave-length. Indeed, since the ratio of solar wave-length to terrestrial wave-length (region of maximum intensity in both cases) is, roughly, 1 to 25, and the ratio of their fourth powers as 1 to $39 \times 10^{-4}$, about, it follows that the interception of outgoing radiation by the very finest and therefore most persistent dust is wholly negligible in comparison with its interception of incoming solar radiation.

*Number of Dust Particles.*—The intensity of the solar radiation, $I_x$, after it has passed through $x$ centimetres of the dust layer of the atmosphere, is given, as previously explained by the equation,

$$I_x = Ie^{-2n\pi x(92)^2 \times 10^{-12}}$$

But, according to numerous observations made during the summer and fall of 1912, when the solar radiation had passed entirely through the dust layer at such an angle that it met, roughly, twice as many dust particles as it would have met had it come in normally, or from the zenith, it was reduced by about 20 per cent. That is to say, under these conditions

$$I_x = 0.8\, I.$$

Hence

$$10 = 8e^{2nx\pi}(92)^2\,10^{-12}$$

Let $nx = 2N$, the total number of particles passed in a cylinder of one square centimetre cross section. Then

$$10 = 8e^{4N\pi}(92)^2\,10^{-12}$$

Hence the number of particles in a vertical cylinder of one square centimetre cross section is given, roughly, by the equation

$$N = 34 \times 10^4.$$

*Temperature Correction Due to Dust Radiation.*—With the number and size of the dust particles known it is easy to determine at least an upper limit to the effect of the direct radiation of the particles themselves on the temperature of the earth.

The temperature of the dust particles, obviously, is very nearly that of the upper atmosphere in which they float, that is, approximately −55° C., or 218° C. absolute. Also, as previously explained, the quantity of radiation from the atmosphere below the isothermal region is substantially that which would be given off by a full radiator at 256° C. absolute.

Now assume the dust particles to be concentrated side by side on a common plane, and, further, assume them to be full radiators —conditions that would raise their effect to the theoretical upper limit. Let $E$ be the intensity or quantity per square centimetre of the outgoing planetary radiation, and $D$ the intensity of the incoming dust radiation. Then

$$E : D = (256)^4 : a(218)^4,$$

in which $a$ is the projected area of all the particles in a vertical cylinder of one square centimetre cross section.

But

$$a = 34\pi\,10^4(92)^2 10^{-12} = 9 \times 10^{-3}.$$

Hence

$$E = 211\,D.$$

Now, when the radiation $D$ is absorbed by the lower atmosphere, it follows that its temperature will be so increased that, when equilibrium is reached, the intensity of its new radiation will be to that of its old as 212 is to 211. Hence $\Delta T$, the ef-

fective temperature increase of the lower atmosphere, is given by the equation

$$\frac{(256 + \triangle T)^4}{(256)^4} = \frac{212}{211},$$

from which

$$\triangle T = 0^\circ.3\ C.$$

But, as stated above, the dust particles, presumably, are not full radiators, and, therefore, probably one-fifth of a degree C. is as great an increase in temperature as may reasonably be expected from this source. But this *increase*, 0.2° C., is small in comparison with the *decrease*, 6° C. to 7° C., caused by the interception of solar radiation, already explained. *Hence it appears reasonably certain that the sum total of all the temperature effects produced by volcanic dust in the upper atmosphere, equal in amount to that put there by the explosion of Katmai, must be, if long continued, a lowering of the surface temperature by several degrees C.*

*Total Quantity of Dust.*—Let $nx = 2N$, the total number of particles passed in a cylinder of one square centimetre cross section. Then, as explained above,

$$10 = 8e^{4N\pi (92)^2 \times 10^{-12}}.$$

Hence

$$N = 34 \times 10^4$$

roughly = number of particles in a vertical cylinder of one square centimetre cross section.

If $A$ is the entire area of the earth in square centimetres, then the total number of dust particles, assuming the dustiness everywhere as just found, is

$$NA = 1734 \times 10^{21}.$$

But the radius of each particle is $92 \times 10^{-6}$ cm., and its volume, assuming it spherical, $33 \times 10^{-13}$ cubic centimetre. Hence the total volume of the dust, assuming the particles spherical, is equal, roughly, to a cube 179 metres, or about 587 feet, on the side, an amount that certainly is not prohibitively large.

As just stated, the total quantity of dust sufficient, as explained, to cut down the intensity of the direct solar radiation by 20 per cent., and therefore, if indefinitely continued, capable, presumably,

of producing an ice age, is astonishingly small—only the 174th part of a cubic kilometre, or the 727th part of a cubic mile, even assuming that the particles are spherical. Since, however, in large measure, the particles are more or less flat, it follows that the actual total mass of the dust necessary and sufficient to reduce the intensity of direct solar radiation by 20 per cent. probably is not more than the 1500th part of a cubic mile, or the 350th part of a cubic kilometre.

Hence, even this small amount of solid material distributed once a year, or even once in two years, through the upper atmosphere, would be more than sufficient to maintain continuously, or nearly so, the low temperature requisite to the production of an ice age; nor would it make any great difference where the volcanoes productive of the dust might be situated, provided only that it was driven high into the isothermal region or stratosphere, since, from whatever point of introduction, the winds of the upper atmosphere would soon spread it more or less evenly over the entire earth.

A little calculation shows, too, that this quantity of dust yearly, during a period of 100,000 years, would produce a layer over the earth only about half a millimetre, or one-fiftieth of an inch, thick, and therefore one could hardly expect to find any marked accumulation of it, even if it had filled the atmosphere for much longer periods.

Whether periods of explosive volcanic activity—and in this case, since the locality of the volcano is a matter of small importance, the whole earth must be considered—occurred at such times as to synchronize with the ice ages and with other epochs of great climatic change is, of course, a problem for the geologist to solve. However, this much appears well-nigh certain: Since the beginning of reliable records, say 160 years ago, the average temperature of the earth has been perceptibly lower, possibly as much as 0.5° C., than it would have been if during all this time there had been no volcanic explosions violent enough to put dust into the isothermal region of the atmosphere. Similarly, on the other hand, if, during this period, violent volcanic explosions had been three or four times more numerous than they actually were, the average temperatures probably would have been 1° C. to 2° C. lower, or low enough, if long continued, to depress the snow line roughly 300 metres, and thus to begin a moderate ice age.

*Effect of Dust on the Interzonal Gradient.*—If $I$ is the initial intensity of radiation of a given wave-length and $aI$ its intensity after passing a unit distance through a homogeneous absorbing or scattering medium, then its remaining intensity, after traveling $n$ units distance through this medium, will be $I\ a^n$. But $n$, in the case of solar radiation passing through the atmosphere, is proportional to the secant of the zenith distance of the sun; and from this in turn it is evident that, in general, variations of dust in the upper atmosphere must change the temperatures of the high latitude regions more than these within the Tropics. Hence, an increase of such dust would steepen the interzonal temperature gradients, strengthen the winds, and make heavier the rain and snowfall, a condition favorable to extensive glaciation. Of course, the increased circulation would, in turn, more or less reduce the new temperature difference, but, nevertheless, a portion, at least, of the increase clearly would remain, and with it the corresponding increases of wind and rain.

## Chapter IV.

### VULCANISM: OBSERVATIONAL.

It will be interesting and profitable now to consider the supplementary portion of the theory of the relation of vulcanism to climate. That is, to consider the observational evidence, pyrheliometric or other kind, bearing on the effect of volcanic dust on solar radiation, and thus obtain some idea of those absolute values essential to even a rough determination of the climatic consequence of volcanic dust in the high atmosphere.

*Pyrheliometric Records.*—Direct measurement of solar radiation by means of the pyrheliometer, an instrument that measures the total heat of sunshine, shows marked fluctuations from year to year in the intensity of this radiation as received at the surface of the earth. This subject has been carefully studied by Dr. H. H. Kimball,[26] of the United States Weather Bureau, who prepared the accompanying table, graphically represented by Fig. 1. Since the yearly values are given in terms of the average value for the entire period, it is obvious that percentages of this average do not represent the full effect of the disturbing causes, of which volcanic dust certainly is the chief.

[26] *M. W. R.*, 46, p. 355, 1918.

| Year | Number of stations | Radiation |
|---|---|---|
| 1883 | 1 | 103 |
| 1884 | 1 | 92 |
| 1885 | 1 | 89 |
| 1886 | 1 | 96 |
| 1887 | 1 | 105 |
| 1888 | 1 | 101 |
| 1889 | 1 | 100 |
| 1890 | 1 | 96 |
| 1891 | 1 | 95 |
| 1892 | 2 | 99 |
| 1893 | 2 | 104 |
| 1894 | 2 | 102 |
| 1895 | 2 | 103 |
| 1896 | 3 | 103 |
| 1897 | 3 | 103 |
| 1898 | 3 | 104 |
| 1899 | 3 | 103 |
| 1900 | 3 | 101 |
| 1901 | 3 | 102 |
| 1902 | 3 | 99 |
| 1903 | 3 | 88 |
| 1904 | 3 | 96 |
| 1905 | 3 | 100 |
| 1906 | 3 | 102 |
| 1907 | 5 | 98 |
| 1908 | 5 | 99 |
| 1909 | 5 | 102 |
| 1910 | 5 | 102 |
| 1911 | 5 | 103 |
| 1912 | 5 | 92 |
| 1913 | 5 | 93 |

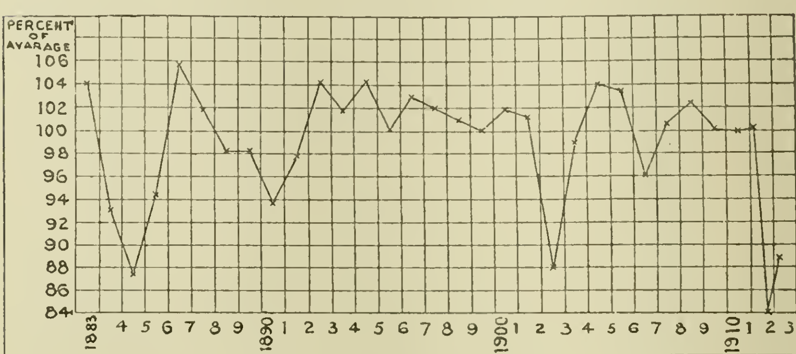
The above table of intensities was computed from observational data obtained at the following stations:

Montpellier, France, monthly means (noon values) .. 1883–1900
Pavlovsk, Russia, monthly maxima .................. 1892–1913
Lausanne, Switzerland, monthly means (noon values) .. 1896–1904
Warsaw, Russia, monthly maxima .................. 1901–1913
Washington, D. C., and Mount Weather, Va., monthly
means for air mass 2.0 ...................... 1905–1913
Simla, India, monthly means (noon values) ........ 1906–1913
Paris, France, monthly maxima .................... 1907–1913

The marked decrease in the pyrheliometric readings for 1884, 1885, and 1886 doubtless were largely, if not almost wholly, due

to the eruption of Krakatoa in the summer of 1883; the decreased values of 1888 to 1892, inclusive, occurred during a period of exceptional volcanic activity, but were probably due essentially to the violent eruptions of Bandaisan (1888), Bogoslof (1890), and Awoe, on Great Sangir (1892); the low values of 1903 to the eruptions of Santâ Maria (1902), Pelé (1902) and Colima (1903); and the low values of 1912–1913, to the explosion, June 6, 1912, of Katmai. The slight depression in the curve corresponding to the year 1907, during which no violent eruptions were reported (this does not exclude the possibility of such

Fig. 1.




Annual average, pyrheliometric values.

occurrence in remote and unfrequented regions), according to Dr. Kimball, probably was caused by local haze at Washington, D. C., where his observations were made, and elsewhere, and this supposition is partially supported by the fact that his values for the year were not uniformly low, and by the further fact, inferred from a publication by Gorczynski,[27] that during that year the solar radiation was but little below normal at Warsaw, Russia.

There is, then, abundant pyrheliometric evidence that volcanic dust in the upper atmosphere actually does produce that decrease in direct solar radiation that theory indicates it should, and, as the theory is well founded and the observations were carefully taken, this mutual confirmation may be regarded as conclusive both of the existence of volcanic dust in the upper atmosphere

[27] *C. R.*, 157, p. 84, 1913.

(isothermal region) and of its efficiency in intercepting direct radiation from the sun.

It should be remembered, however, in this connection, that the intensity of the solar radiation at the surface of the earth depends not only upon the dustiness of the earth's atmosphere, but also upon the dustiness, and, of course, the temperature, of the solar atmosphere.

Obviously, dust in the sun's envelope must more or less shut in solar radiation just as, and in the same manner that, dust in the earth's envelope shuts it out. Hence it follows that when this dust is greatest, other things being equal, the output of solar energy will be least, and when the dust is least, other things being equal, the output of energy will be greatest. Not only may the intensity of the emitted radiation vary because of changes in the transparency of the solar atmosphere, but also because of any variations in the temperature of the effective solar surface, which, it would seem, might well be hottest when most agitated, or at the times of spot maxima, and coolest when most quiescent, or at the times of spot minima.

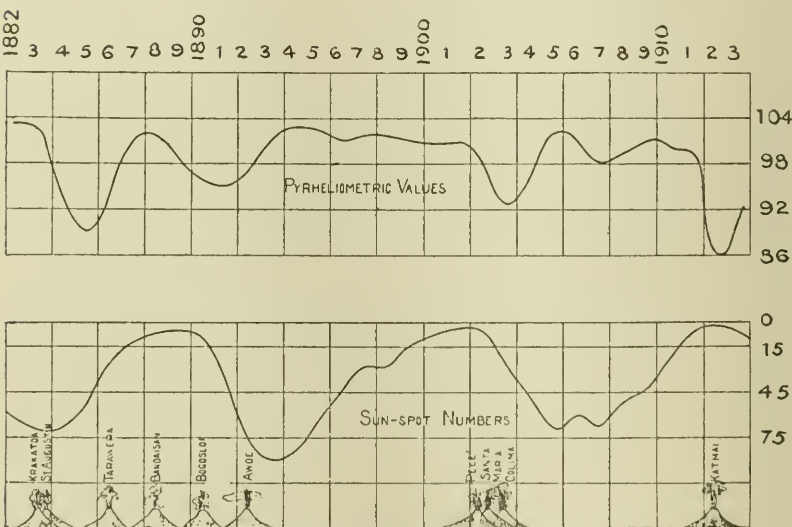
Now, the dustiness of the solar atmosphere, manifesting itself as a corona, certainly does vary through a considerable range from a maximum when the sun-spots are most numerous to a minimum when they are fewest, and, therefore, partly because of changes in the transparency of the solar envelope, and partly because of changes in the solar surface temperatures, if, as in all probability they do, such temperature changes take place, we should expect the solar constant also to vary from one value at the time of spot maximum to another at the time of spot minimum, and to vary as determined by the controlling factor, dust or temperature.

If the above reasoning is correct, it follows that pyrheliometric readings are functions of, among other things, both the solar atmosphere and our own terrestrial atmosphere; and as the former is altered chiefly by sun-spots or at least varies with their production and existence, and the latter by volcanic explosions, a means is at hand for comparing the relative importance of the two radiation screens.

Fig. 2 shows one such comparison. The upper curve gives smoothed annual average pyrheliometric readings (not solar constants, though closely proportional to them) and the lower curve

sun-spot numbers. It will be noticed that in their most pronounced features the two curves have but little in common, and that the great drops in the pyrheliometric values occur simultaneously with violent volcanic explosions, as already explained, and not at the times of sun-spot changes. *Hence it appears that the dust in our own atmosphere, and not the condition of the sun, is a very important, if not the controlling, factor in determining the magnitudes and times of occurrence of great and abrupt changes of insolation intensity at the surface of the earth.*

Fig. 2.




Relation of pyrheliometric values to sun-spot numbers and volcanic eruptions.

*Temperatures at the Surface of the Earth.*—If a veil of dust actually should intercept as much as one-fifth of the direct solar radiation, as Fig. 1 indicates that at times it does, it would seem that in those years the temperature of the atmosphere at the surface of the earth should be somewhat below the normal. Of course, the great supply of heat in the ocean would produce a lag in this effect, particularly over the oceans themselves, and, besides, there must be both an increase of sky light by scattering and some interception of earth radiation by the dust which, since it is at great altitudes, receives the full, or nearly the full, planetary radiation of the earth. This increase of sky radiation, together with the return terrestrial radiation, obviously compensates in

some measure for the loss of direct insolation. However, measurements made by Abbot[28] at Bassour, Algeria, during the summer of 1912, show that at this time and place the direct radiation and the sky radiation, which obviously included both the scattered solar radiation and some return terrestrial radiation, were together less by about 10 per cent. than their normal combined values; and there is no reason to think that in this respect Bassour was at all different from other places, certainly a large portion of the northern hemisphere, at least, covered by the veil of dust. Clearly, then, if this decrease in the radiation received were universal and should continue indefinitely, the ultimate radiation of the earth would also decrease to the same extent, or 10 per cent. Now, since the earth, or rather the water vapor of the atmosphere, radiates substantially as a black body and, therefore, proportionally to the fourth power of its absolute temperature, it follows that a 10 per cent. change in its radiation would indicate about a 2.5 per cent. change in its temperature. But the effective temperature of the earth as a full radiator, which it closely approaches, is about 256° A.[29] Hence a change of 10 per cent. in the radiation emitted would imply 6.4° C. change in temperature, an amount which, if long enough continued, would be more than sufficient to produce glaciation equal probably to the most extensive of any known ice age.

As above implied, not much lowering of the temperature could be expected to take place immediately; however, some early cooling over land areas might well be anticipated. To test this point the temperature records of a number of high altitude (together with two or three very dry) inland stations have been examined. High altitudes were chosen because it was thought that the temperature effects of dust in the upper atmosphere probably are most clearly marked above the very and irregularly dusty layers of the lower atmosphere; and the condition that the stations should also be inland was imposed because these are freer, presumably, than many coast stations, from fortuitous season changes. Thus, stations in the eastern portion of the United States were rejected because of the great differences in the winters, for example, of this section depending upon the prevailing direction

[28] *Smithsonian Miscellaneous Collections,* vol. lx, No. 29, 1913.

[29] Abbot and Fowle, *Annals Astrophys. Obsy.,* Smithsonian Institution, vol. ii, p. 175, 1908.

of the wind,[30] a condition wholly independent, so far as known, of variations in the intensity of direct radiation.

The number of stations was still further limited by the available recent data. Hence the records finally selected, and kindly put in shape by the Climatological Division of the United States Weather Bureau, Mr. P. C. Day in charge, were obtained at the following places:

Table II.

*Stations Whose Data Were Used.*

| Name. | Latitude. | Longitude. | Elevation in feet. |
|---|---|---|---|
| AMERICA. | | | |
| Baker | 44° 46′ N. | 117° 50′ W. | 3,466 |
| Bismarck | 46° 47′ N. | 100° 38′ W. | 1,674 |
| Cheyenne | 41° 08′ N. | 104° 48′ W. | 6,088 |
| Denver | 39° 45′ N. | 105° 00′ W. | 5,291 |
| Dodge City | 37° 45′ N. | 100° 00′ W. | 2,509 |
| El Paso | 31° 47′ N. | 106° 30′ W. | 3,762 |
| Helena | 46° 34′ N. | 112° 04′ W. | 4,110 |
| Huron | 44° 21′ N. | 98° 14′ W. | 1,306 |
| North Platte | 41° 08′ N. | 100° 45′ W. | 2,821 |
| Red Bluff | 40° 10′ N. | 122° 15′ W. | 332 |
| Sacramento | 38° 35′ N. | 121° 30′ W. | 69 |
| Salt Lake City | 40° 46′ N. | 111° 54′ W. | 4,360 |
| San Antonio | 29° 27′ N. | 98° 28′ W. | 701 |
| Santa Fé | 35° 41′ N. | 105° 57′ W. | 7,013 |
| Spokane | 47° 40′ N. | 117° 25′ W. | 1,929 |
| Winnemucca | 40° 58′ N. | 117° 43′ W. | 4,344 |
| Yuma | 32° 45′ N. | 114° 36′ W. | 141 |
| EUROPE. | | | |
| Mont Ventoux | 44° 10′ N. | 5° 16′ E. | 6,234 |
| Obir | 46° 30′ N. | 14° 29′ E. | 6,716 |
| Pic du Midi | 42° 56′ N. | 0° 8′ E. | 9,380 |
| Puy de Dôme | 45° 46′ N. | 2° 57′ E. | 4,813 |
| Säntis | 47° 15′ N. | 9° 20′ E. | 8,202 |
| Schneekoppe | 50° 44′ N. | 15° 44′ E. | 5,359 |
| Sonnblick | 47° 3′ N. | 12° 57′ E. | 10,190 |
| INDIA. | | | |
| Simla | 31° 6′ N. | 77° 12′ E. | 7,232 |

In Table III the first column gives the year in question. The second column gives the average departure in degrees F., for the seventeen American stations, of the annual average maximum, as determined from the monthly average maxima, from the normal annual maximum, or average of a great many annual average maxima. The third column gives smoothed values, determined from the actual values in the second column as follows:

[30] Humphreys, *Monthly Weather Review*, vol. xlii, p. 672, 1914.

$$S = \frac{a + 2b + c}{4},$$

in which $S$ is the smoothed value, $b$ the actual value pertaining to the particular year for which $S$ is being computed, $a$ and $c$ the actual values for the next previous and the next succeeding years, respectively. The fourth and fifth columns give, respectively, the actual and the smoothed average departures of the annual average minima, while the sixth and seventh columns give the corresponding average departures of the annual average means.

TABLE III.

*Average Temperature Departures from Temperature Normals.*

AMERICA.

| Year. | Maxima. | | Minima. | | Means. | |
|---|---|---|---|---|---|---|
| | Actual. | Smoothed. | Actual. | Smoothed. | Actual. | Smoothed. |
| 1880 | −1.3 | +0.03 | −1.8 | −0.68 | −1.7 | −0.50 |
| 1881 | +0.2 | −0.30 | +0.6 | −0.20 | +0.1 | −0.48 |
| 1882 | −0.3 | −0.50 | −0.2 | −0.20 | −0.4 | −0.50 |
| 1883 | −1.6 | −1.33 | −1.0 | −0.70 | −1.3 | −1.15 |
| 1884 | −1.8 | −1.20 | −0.6 | −0.28 | −1.6 | −1.05 |
| 1885 | +0.4 | −0.18 | +1.1 | +0.43 | +0.3 | −0.30 |
| 1886 | +0.3 | +0.35 | +0.1 | +0.10 | −0.2 | −0.03 |
| 1887 | +0.4 | +0.38 | −0.9 | −0.45 | 0.0 | +0.07 |
| 1888 | +0.4 | +0.53 | −0.1 | −0.13 | +0.5 | +0.53 |
| 1889 | +0.9 | +0.63 | +0.6 | +0.23 | +1.1 | +0.85 |
| 1890 | +0.3 | +0.15 | −0.2 | −0.05 | +0.7 | +0.58 |
| 1891 | −0.9 | −0.58 | −0.4 | −0.38 | −0.2 | +0.05 |
| 1892 | −0.8 | −0.85 | −0.1 | −0.33 | −0.1 | −0.20 |
| 1893 | −0.9 | −0.73 | −0.7 | −0.38 | −0.4 | −0.08 |
| 1894 | −0.3 | −0.55 | +0.4 | −0.18 | +0.6 | +0.13 |
| 1895 | −0.7 | −0.35 | −0.8 | −0.08 | −0.3 | +0.25 |
| 1896 | +0.3 | −0.18 | +0.9 | +0.28 | +1.0 | +0.45 |
| 1897 | −0.6 | −0.30 | +0.1 | +0.13 | +0.1 | +0.28 |
| 1898 | −0.3 | −0.65 | −0.6 | −0.45 | −0.1 | −0.13 |
| 1899 | −0.8 | −0.13 | −0.7 | −0.10 | −0.4 | +0.25 |
| 1900 | +1.4 | +0.78 | +1.6 | +0.90 | +1.9 | +1.23 |
| 1901 | +1.1 | +0.83 | +1.1 | +1.08 | +1.5 | +1.35 |
| 1902 | −0.3 | −0.13 | +0.5 | +0.38 | +0.5 | +0.53 |
| 1903 | −1.0 | −0.43 | −0.6 | −0.05 | −0.4 | +0.18 |
| 1904 | +0.6 | −0.15 | +0.5 | +0.05 | +1.0 | +0.38 |
| 1905 | −0.8 | −0.30 | −0.2 | +0.08 | −0.1 | +0.33 |
| 1906 | −0.2 | −0.30 | +0.2 | +0.08 | +0.5 | +0.33 |
| 1907 | 0.0 | +0.10 | +0.1 | +0.10 | +0.4 | +0.50 |
| 1908 | +0.6 | +0.15 | 0.0 | −0.08 | +0.7 | +0.43 |
| 1909 | −0.6 | +0.38 | −0.4 | −0.05 | −0.1 | +0.55 |
| 1910 | +2.1 | +0.80 | +0.6 | +0.08 | +1.7 | +0.75 |
| 1911 | −0.4 | +0.03 | −0.5 | −0.35 | −0.3 | +0.05 |
| 1912 | −1.2 | −0.70 | −1.0 | −0.63 | −0.9 | −0.53 |

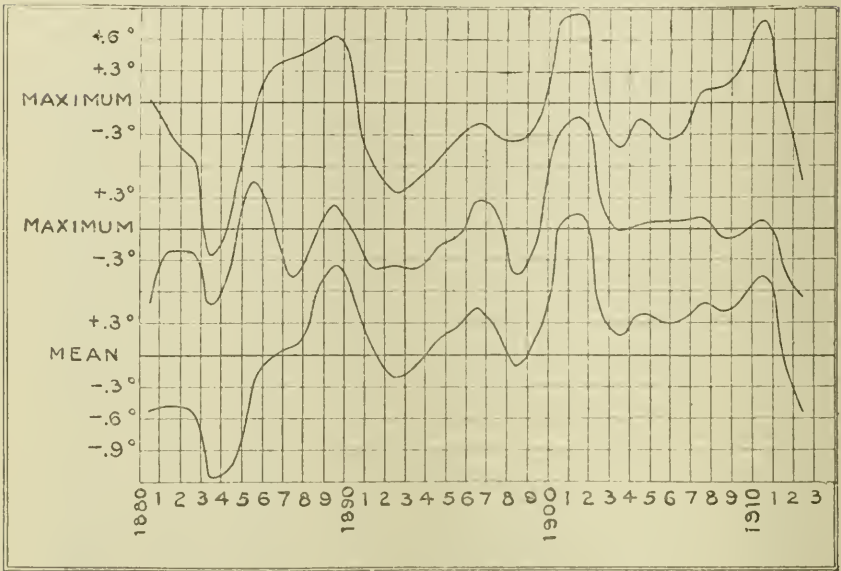
Fig. 3 shows the graphical equivalents of the smoothed portions of Table III.

It will be noticed that the three curves of Fig. 3, marked

maximum, minimum, and mean, respectively, are, in general, quite similar to each other. Hence, because of this mutual check and general agreement, it seems reasonably certain that any one set of temperature data, the means, for instance, furnishes a fairly safe guide to the actual temperature and climatic fluctuations from year to year or period to period.

Table IV gives the weighted actual average departures and the smoothed departures in degrees F. of the annual mean tem-

FIG. 3.




Smoothed averages of the annual average temperature departures of 17 American stations.

peratures of the selected seventeen American, seven European, and one Indian stations listed in Table I.

The average departures were calculated in accordance with the more or less correctly coefficiented equation,

$$D = \frac{4A + 2E + I}{7},$$

in which $D$ is the weighted departure, $A$ the smoothed average American, $E$ the smoothed average European, and $I$ the smoothed Indian, departure of the mean annual temperature from the normal annual temperature.

*(To be concluded)*

## NOTES FROM THE U. S. BUREAU OF STANDARDS.*

### MATERIALS AND METHODS USED IN THE MANUFACTURE OF ENAMELED CAST-IRON WARES.[1]

By Homer F. Staley.

[ABSTRACT.]

This is a comprehensive treatise dealing with the various phases of the technology of manufacturing enameled cast-iron wares. It is the first publication dealing fully with this subject in any language.

The paper deals particularly with the coating of cast iron with white vitreous enamels by the American or dry-powder process. In this method of manufacture, the thoroughly cleaned castings are painted with a suspension in water of powdered glass, clay and other materials. This suspension is known as the ground coat. The castings are then heated until the ground coat is thoroughly fused, forming an extremely thin layer of transparent glass on the castings. The ware is then withdrawn from the furnace and immediately coated by means of long-handled sieves with a layer of white, opaque, powdered glass, known as the cover coat enamel. Next the castings are returned to the furnace, and in a couple of minutes the cover coat enamel fuses to a smooth layer. Two such layers of cover coat enamel are usually applied, giving a total thickness of from $^1/_{32}$ to $^1/_{16}$ of an inch. The paper does not discuss the enameling of cast iron with wet coat cover enamels.

Several sections are devoted to a discussion of the preparation and testing of the various chemicals and minerals used in compounding enamels and to the effect each of these has on the physical and chemical properties of enamels. The methods employed in making and cleaning the castings are described in detail. beginning with construction of patterns and ending with sand blasting and polishing. The methods and equipment, including furnaces, used in preparing enamels and applying them to castings are covered in two sections. Sections are devoted to the control of the

* Communicated by the Director.

[1] Technologic paper 142.

lustre of enamels, the cause and control of crazing, and to the methods to be used in avoiding blisters, pin holes and other minor defects. Typical formulas are given for ground coat enamels, cover coat enamels containing oxide of tin, and for those containing antimony compounds as the opacifying agent. These formulas are each stated in terms of raw batch for 1000 pounds melted enamel, of percentage composition and of empirical chemical formula. The calculations involved in arriving at each form of expression are explained in detail.

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## A STUDY OF THE DETERIORATION OF NICKEL SPARK PLUG ELECTRODES IN SERVICE.[2]

By Henry S. Rawdon and A. J. Krynitzky.

[ABSTRACT.]

The electrodes of spark plugs are usually made of commercial nickel wire, 97 per cent. grade being a common material. After considerable service, the electrodes show different types of deterioration. A peculiar one which occurs only in the side electrodes is the formation of transverse "knife-cut" breaks together with the intergranular embrittling of the metal adjacent to the break; a gradual widening of the breach results as a consequence. Such breaks were found only in the side electrodes which are firmly anchored at both ends. The central electrode shows an embrittling of the surface metal only at the extreme tip, as is also true of the type of side electrodes which are anchored at only one end.

This characteristic embrittling of the nickel wire appears to be due to a combination of causes. Microscopic examination of the deteriorated wires shows a complete network of intercrystalline fissures in the embrittled portions after etching. Often intercrystalline cracks extend deep into the wire. The cohesion between the adjacent grains is greatly weakened and crystals often fall bodily out of place upon slight etching.

Continuous heating of nickel wires for several days at a high temperature (approximately 850° C., 1562° F.) develops an intercrystalline eutectic-like network, apparently of oxide, in the outer zone of the wire. While this aids in the embrittling of such wires, it probably does not contribute to the deterioration of the electrodes of spark plugs. Heating in reducing gases,

[2] Technologic paper 143.

similar to those encountered in service, develops a similar intergranular network. Intense local heating, by means of the electric spark, does likewise in a small overheated zone. Both of these causes probably contribute materially to the embrittling of the electrodes in service.

The application of a relatively very low tensional stress (approximately 5 per cent. of the ultimate strength of the normal material) was found sufficient to fracture nickel wires when hot. Wires broken in this way show a sharp crystalline fracture with no elongation whatever and in every respect the appearance is identical with the breaks produced in service. The central electrode is found to deteriorate much less than the side ones. The latter, when anchored at both ends across the shell of the plug, are subject to tensional stress due to the differential expansion of the shell and hence the cracks develop quite readily. Evidently this deterioration of nickel wire is a characteristic behavior of this material at high temperatures.

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## THE CADMIUM ELECTRODE FOR STORAGE BATTERY TESTING.[3]

By H. D. Holler and J. M. Braham.

[ABSTRACT.]

IN the operation and testing of storage cells, it is frequently important, particularly in cases of low capacity, to know the individual potentials of the positive and negative plates of the cell. No standard method of measuring the potentials of storage battery plates is recognized, but for many years the common method has consisted in measuring the potential differences between either plate and a piece of metallic cadmium with an ordinary voltmeter. This method often leads to contrary results and voltmeters vary greatly in resistance. The Bureau undertook this investigation to determine the accuracy of the cadmium electrode and the errors to which it is subject. As a standard electrode, the mercurous sulphate half-cell was adopted after experiments which showed it to be well adapted to the purpose. The reproducibility of the cadmium electrode was first determined and then the effect of temperature, the effect of drying the electrodes and the polari-

[3] Technologic paper 146.

zation of the electrode were studied. The constancy of the cadmium electrode during measurements of the potentials of storage battery plates when on charge and discharge was also determined. This investigation deals only with the accuracy of the cadmium electrode and does not discuss the cadmium readings with reference to the age or the condition of the battery.

The most important error found was due to the polarization of the electrode but this error can be easily avoided if the electrode is used to measure the potential of the negative plate from which the potential of the positive plate may be calculated if the cell voltage is known. This is contrary to the way the electrode is generally used, but it eliminates the chief error which arises when the ordinary voltmeter is employed to measure the voltage.

## THE DEPENDENCE OF THE INPUT IMPEDANCE OF A THREE-ELECTRODE VACUUM TUBE UPON THE LOAD IN THE PLATE CIRCUIT.[4]

By John M. Miller.

[ABSTRACT.]

Because of the capacities between the electrodes of three-electrode vacuum tube, the input impedance, which determines the input voltage supplied to the grid of the tube by the apparatus in the input circuit, depends upon the electrical characteristics of the plate or output circuit. In this paper theoretical relations are established which permit the input impedance to be calculated when the impedance in the plates circuit is known. These relations are also checked by experiment.

## THERMAL EXPANSION OF INSULATING MATERIALS.[5]

By Wilmer H. Souder and Peter Hidnert.

[ABSTRACT.]

This paper gives data on a few materials possessing irregular or unusual expansive properties.

In most cases the expansions are too irregular to justify the use of the general quadratic equations.

[4] Scientific paper 351.

[5] Scientific paper 352.

A knowledge of the thermal behavior of these materials is essential before assembling them in certain types of apparatus subjected to wide temperature variations.

The most striking peculiarities are:

(*a*) The wide range in the values of the coefficient of porcelain (from 1.6 to 19.6 millionths per unit length per degree Centigrade).

(*b*) The three varieties of expansions for porcelain; namely, straight line, concave and convex expansion curves.

(*c*) The shrinkage and the loss in weight of the phenol and similar compounds when subjected to excessive heat treatment.

(*d*) The permanent growth and variations of different marbles when subjected to heat treatment.

(*e*) The negative coefficient of expansion of marble at low temperatures.

## VARIATION IN DIRECTION OF PROPAGATION OF LONG ELECTROMAGNETIC WAVES.[6]

By a Hoyt Taylor, U. S. Naval Aircraft Laboratory.

[ABSTRACT.]

The observed direction of radio waves as obtained with a direction-finder varies with time, when long waves are used such as those of very high-power stations. The variations of direction are of the order of 90° for very long waves. No such large variations are found for short damped waves produced by spark apparatus. A method of increasing the sharpness of determination of direction has been worked out. A theoretical explanation of the variations of directions is given, based on the existence of media in the earth's atmosphere capable of reflecting and refracting the waves.

## PRINCIPLES OF RADIO TRANSMISSION AND RECEPTION WITH ANTENNA AND COIL AERIALS.[7]

By J. H. Dellinger.

[ABSTRACT.]

Coil aerials are coming to replace the large antennas in radio work. The advantage of the coil aerial as a direction-finder interference preventer, reducer of strays and submarine aerial, make it

[6] Scientific paper 353.

[7] Scientific paper 354.

important to know how effective such an aerial is as a transmitting and receiving device in comparison with the ordinary antenna. In this article the mathematical theory is presented and, as a result, the answer to this question is obtained. Experiments have verified the conclusions reached, and the formulas which are obtained are a valuable aid in the design of an aerial to fit any kind of radio station.

A great many questions and hazy ideas on the behavior of radio waves are cleared up by the study which was made and here presented.

It is found that the coil aerial is particularly desirable for communication on short wave-lengths. A coil aerial is as powerful as an antenna only when its dimensions approach those of the antenna. For other reasons, however, a small coil aerial is in many cases as effective as a large antenna.

It is shown that an advantageous type of radio aerial is a condenser consisting of two large metal plates. This type of aerial has many of the advantages of the coil aerial.

The fundamental principles of design of aerials are given in this paper. On the basis of this work the actual functioning of any type of radio aerial can be determined either from measurements made upon the aerials or from actual transmission experiments.

The investigation has opened up a large and most interesting field for further research and progress in the utilization of radio waves.

## DETERMINING THE OUTPUT CHARACTERISTICS OF VACUUM-TUBE GENERATORS.[8]

By Lewis M. Hull.

[ABSTRACT.]

The direct-coupled, Hartley circuit can be taken as typical of the circuits used in connection with the three-electrode vacuum tube for the purpose of generating oscillations. The grid and filament of the tube in this particular circuit are connected to the branched circuit containing inductance and capacity in such a manner as to include a portion of the inductance of that circuit; the rest of the inductance of the circuit is included between the

[8] Scientific paper 355.

plate and filament, while a capacity and resistance, representing the antenna, is connected between grid and plate. Power is supplied to the circuit from a high-voltage battery or generator, which is connected in series with the plate, filament, and branched output or oscillatory circuit. When the system is in oscillation, power from the direct-current source is converted into oscillating-current power; the oscillating current flows in series through the capacity and coils of the branched circuit, its wave form being practically sinusoidal, and its frequency of oscillation being the natural or resonant frequency of the branched circuit. This current induces sinusoidal oscillating voltages across the plate and grid coils having a definite constant ratio of amplitudes, and so related as to phase that when the grid is $e$ volts positive or negative with respect to the filament, the plate is $(E_b - ne)$ volts positive or $(E_b + ne)$ volts positive, $E_b$ being the steady supply voltage, and $n$, the ratio of plate and grid coupling reactances. Under the influence of these sinusoidal voltages a pulsating electron current flows in the grid-filament circuit whose fundamental constituent is in phase with the alternating grid voltage; this current represents a withdrawal of power from the output circuit. Likewise a pulsating current flows in the plate-filament circuit whose fundamental constituent is opposite in phase to the alternating component of plate voltage; this current supplies power to the output circuit. A conduction of stability ensues when the power supplied by the fundamental of plate current minus the power dissipated by the fundamental of grid current is just equal to the power dissipated by the output current in the resistance of the antenna.

The fundamental constituents of the electron currents which will be supplied by a given tube under the action of sinusoidal plate and grid voltages can be computed as functions of these voltages from a family of "static characteristics" of the tube which are obtained by varying these voltages step by step and measuring the resulting steady values of current. The effective power output is

$$P_o = \frac{nE_g}{2}\left( I_p - \frac{1}{n} I_g \right)$$

where $E_g$ is the amplitude of grid voltage and $I_p$ and $I_g$ are the amplitudes of the fundamentals of plate and grid currents, respectively. The efficiency is

$$Y = .5\,\frac{E_g}{E_b}\left( \frac{nI_p - I_g}{oI_p} \right)$$

where $E_b$ is the steady supply voltage and $oI_p$ is the reading of a direct current ammeter in the plate circuit.

From the current characteristics the power output can be obtained graphically as a function of the grid voltage:

$$P_o = f(E_g)$$

Moreover,

$$E_g = L_g \sqrt{\frac{P_o}{RCL}}$$

Where $L_g$ is the grid inductance and $R$, $C$, $L$, are the total resistance, inductance, and capacity of the antenna circuit. A simultaneous graphical solution of these two equations gives the power output from the tube as a function of any of the three electrical constants of the output circuit.

Such solutions can be obtained graphically for any type of tube whose static characteristics are known.

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**Twenty-three Types of Optical Glass.** R. J. MONTGOMERY. (*American Ceramic Society,* September 24, 1919.)—A distinction should be made between optical and other kinds of glass. By the word optical we mean those glasses which are selected for certain purposes because of their behavior toward transmitted light. This behavior is primarily due to its composition and not to its shape. Measurements of the index of refraction and dispersion classify the optical glasses into sub-divisions. In ordinary glass the composition may be changed to obtain satisfactory melting qualities, but in optical glass each change in composition will change the optical properties. On this account optical glass is much more difficult to make as the optical properties must be held constant within very narrow limits.

One hundred or more optical glasses have been listed, but practically all of them may be placed in 23 groups. The ones in each group are quite similar in composition and in method of manufacture. They may be shown graphically by plotting the index of refraction against dispersion on coördinate paper. The index of refraction may vary from about 1.45 to 1.96, while the dispersion may vary from about 20.0 to 70.0. From the plotted information it is easy to determine the fields in which each glass constituent is used in the largest amount. We, therefore, have the lead field, the barium field, the soda-lime field, the boric acid field, etc. Approximate compositions are apparent and new glasses may be developed by interpolation between the compositions of known glasses.

# NOTES FROM THE LABORATORY, GENERAL ELECTRIC COMPANY.*

## THE IONIZATION GAGE.

By S. Dushman and C. G. Found.

[ABSTRACT.]

I. *Construction and Calibration.*—The design used by the writers consists of two concentric tungsten filaments inside a coaxially situated cylinder. The inner filament is used as a source of electrons with the outer one as anode, while the cylinder is used as positive ion collector. The gage was calibrated by a "flow" method, (based on Knudson's formula for the flow of gases through capillaries) for extremely low pressure, and it was found that the electron emission is proportional to the pressure over a range which extends from over 10 bars to $10^{-3}$ bars, and it is, therefore, probably certain that this same relation holds at the lowest attainable pressures.

II. *Relation between Ionization Current at Constant Pressure and Number of Electrons per Molecule of Gas.*—Calibration of the gage with different gases led to the interesting relation that the number of positive ions formed at constant electron emission and constant pressure is proportional to the number of electrons per molecule of the gas ionized. It is possible, therefore, by this method to determine *molar numbers* for different gases. By molar number is meant the sum of the products, atomic number times number of atoms taken for each atom in the molecule. Thus the molar number of iodine is $2 \times 53 = 106$; and for $HgI_2$ it is $80 + 2 \times 53 = 186$. Vapor pressure determinations of both these substances gave results agreeing with the above values for the molar numbers. If it be assumed that ionization is due to collisions between thermions and electrons in the atoms, it is possible to calculate the mean free path of an electron in any gas at a given pressure, and also the effective diameter of the electron. For argon at 1 bar pressure and room temperature, the mean free path is about 150 cm., and the diameter of the electron is calculated on this basis as about $4.4 \times 10^{-9}$ cm.

* Communicated by the Director.

**Biochemical Studies of the Diet.**—In a paper on the relation of the diet to pellagra, E. V. McCOLLUM (*Proceedings of the American Philosophical Society,* 1919, vol. lviii, pp. 41–54) gives a summary of recent biochemical discoveries concerning a satisfactory diet. The diet must furnish sufficient energy in the form of carbohydrates, fats and proteins, an adequate supply of mineral food or ash in suitable combinations, and a sufficient amount of the two food hormones, or vitamines fat-soluble A and water-soluble B. The proteins must be suitable in both quality and quantity; quantitatively the ration should contain a liberal amount of protein; qualitatively the value of a protein depends on its source, those of the navy bean or pea are less valuable than those of the cereal grains, and these in turn less valuable than those of milk. The food hormones are dietary essentials, as yet unidentified chemically; absence of fat-soluble A from the diet produces a diseased condition of the eye known as xerophthalmia, while absence of water-soluble B gives rise to the disease beri-beri. A satisfactory diet cannot be obtained from mixtures of seeds or products obtained by their milling with tubers, edible roots, and cuts of meat consisting of muscle; in addition one or more of the protective foods must be eaten. The group of protective foods includes milk, eggs, and leafy vegetables; by virtue of their inorganic content of fat-soluble A, and the quality of their proteins, they insure the presence of a sufficient amount of these ingredients in the diet if they be used in sufficient quantity; they thereby protect the health, hence their name protective foods. If foodstuff or mixture of foodstuffs may be analyzed by the biological method, it is fed to a group of animals, such as rats, while other groups receive it supplemented by pure protein, or salts, or a food hormone, etc., the influence of the various rations on the weight and health of the experimental animals is then observed. Pellagra is caused by an infectious agent, and not by a faulty diet, however such a diet may increase the susceptibility to this disease. J. S. H.

**Steel Disk Automobile Wheels.** (*Scientific American,* vol. cxxi, p. 225, September 6, 1919.)—There is a growing tendency on the part of motorists to favor the pressed steel disk wheel and increasing numbers of fine cars are being equipped with traction and support members of this type. The wheel used for passenger cars is a single disk type, being dished for strength. In most designs the thickness of the metal is greater at the centre than at the rim, thus proportioning the section to the strain coming upon it. A cast-steel master hub is fastened to the axle, and the steel disk is attached to this by four easily removable nuts which screw on studs in the permanent hub flange. The disk wheel is as easily removed as any other type and is stronger and more easily washed than the conventional wood or wire spoked forms.

## NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

### PHTHALIC ANHYDRIDE. I. INTRODUCTION.[1]

By H. D. Gibbs.

[ABSTRACT.]

PHTHALIC ANHYDRIDE, a valuable intermediate for the manufacture of certain important dyes and medicinals, is usually made by the oxidation of naphthalene by means of sulphuric acid in the presence of mercury compounds as catalysts. This method is not as satisfactory as might be desired, since the yields are poor and erratic, generally averaging about 25 per cent. theoretical but occasionally running as high as 55 per cent.

It had been previously found that toluene vapors can be oxidized by passing a mixture of them with oxygen or air heated to a temperature varying from the boiling point of toluene to 550° C. over oxides of the fifth and sixth groups of the periodic system, especially vanadium oxide and molybdenum oxide. Under these conditions the toluene is oxidized to benzaldehyde and benzoic acid, the former predominating. Similar reactions with (1) naphthalene vapors and air produce phthalic anhydride, with (2) anthracene and air, anthraquinone and with (3) phenanthrene and air, phenanthraquinone. Since the demand for phthalic anhydride was acute, this problem was the first one thoroughly investigated.

The best laboratory yield was 82 per cent. theoretical, or about 95 grams of phthalic anhydride from 100 grams of naphthalene. A small scale factory unit set up in the laboratory produced about 150 grams of phthalic anhydride in one hour. A notable fact in regard to this method is the remarkable degree of purity of the phthalic anhydride.

The Department of Agriculture is coöperating with chemical manufacturers on this process, which, it is believed, once all the details are worked out, will be the most economical and practicable method known for making phthalic anhydride, and this compound may become one of the cheapest organic compounds.

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* Communicated by the Chief of the Bureau.

[1] Published in *J. Ind. Eng. Chem.*, vol. xi, No. 11, Nov., 1919, pp. 1031, 1032.

**Scientific Research in Relation to the Glass Industry.** EDWARD W. WASHBURN. (*American Ceramic Society*, September 29, 1919.)—With the development of methods of producing, controlling and measuring high temperatures in the laboratory our knowledge of the chemistry and physics of high temperature processes has steadily increased and applications of that knowledge have naturally followed. The stimulus of the war has aided greatly in bringing together the practical man of the factory and the scientist of the laboratory. But in glass-making we know *how* to-day much better than we know *why*. Progress demands that we know why. In industrial laboratories the work to be done may be roughly classified under three headings: (1) Routine testing of raw materials and products and similar control work; (2) works problems, including the curing of troubles and the improvement of processes and products; (3) fundamental research to find out the *why* of the operations or to secure quantitative scientific data covering materials, processes and products In the glass industry almost all of the fundamental research work remains to be done. For example, very little is known of the relations between (1) viscosity and (2) temperature and composition, although viscosity has long been recognized as of great importance in making and working glass. Surface tension and vapor pressure and even density have scarcely been studied at all. Of the reactions and compounds we know almost nothing. The nature of gases remaining in solution is almost unknown, as well as their effect, if any, on the properties of the glass. Many unanswered questions are referred to, including relations between composition and properties, cause of greenish color resulting from substituting soda for potash, the condition of copper in glass, the cause of pink color from manganese, and red in chrome pink, the function of arsenic. There are three types of laboratories to carry out such researches: (1) industrial, (2) government or research foundations, and (3) university. The endowment of research professorships in glass would have a very stimulating effect.

**The Penetration of Iron by Hydrogen.** T. S. FULLER. (*American Electrochemical Society*, 1919.)—The results are given of experiments showing the effect of various conditions on the penetration of iron by nascent hydrogen at temperatures from 20° to 100° C. Hydrogen was generated on the outside of an iron tube by immersing the tube in a solution, and the volume of gas penetrating to the inside of the tube was measured. The rate was greater for a unit immersed without electrical connections than when the unit was used as a cathode, but in the latter case the greater the current the greater the penetration. The rate also increases with the temperature. Copper is not penetrated, but a coating of tin on the iron increases the rate. The effects of other conditions are shown.

G. F. S.

## NOTES FROM THE U. S. BUREAU OF MINES*

### WHY AND HOW COKE SHOULD BE USED FOR DOMESTIC HEATING.

By Henry Kreisinger and A. C. Fieldner.

Coke should be used for domestic heating because it is a smokeless fuel. Estimates of the cost of smoke to the community are given as $12 per capita per year in Cleveland and $20 per capita per year in Pittsburgh. The use of small sizes of coke for domestic heating gives a better return to the coke producers and encourages the production of coke and its by-products, which is an advantage to the nation as compared to burning raw bituminous coal as fuel. It makes more gas available to the householder, with its resulting convenience and economy. The ammonia that is made as a by-product of coke is used for fertilizer and helps to keep down the price of food. Coal-tar from coking furnaces is the raw material from which many drugs, dyes, paints, preservatives, roofing, road dressing and a myriad of other substances are made. Increasing the supply of the raw material helps keep down the price of the finished product. In addition, a coke fire is easier to tend and makes less dirt in the house. Learning how to manage a fire when coke is burned is a relatively simple matter that is described in detail in Technical Paper 242, Bureau of Mines, which is sent free on request.

### THE VAPOR PRESSURE OF LEAD CHLORIDE.

By E. D. Eastman and L. H. Duschak.

The vapor pressure of the chloride of lead, and of other metals with which it is associated in nature, is a matter of interest to the metallurgist because it seems possible that the problem of economical treatment of the complex ores of lead, zinc, silver, and copper may be solved through the use of processes involving a chloridizing roast and subsequent volatilization of part or all of the valuable metallic constituents. To successfully develop such processes an

* Communicated by the Director.

accurate knowledge of the fundamental data, such as vapor pressures of the metals involved, is essential.

The material to be studied was heated in a hand-regulated electrical furnace, using an apparatus devised for the purpose. The heating was carried on in an atmosphere of nitrogen, prepared by the Lupton method. The weight of lead chloride recovered was determined by steaming out the condenser tube and titrating for chloride by the Volhard method.

The results of the investigation are given in Technical Paper 225 of the Bureau of Mines. They form a smooth curve between the values of 0.141 mm. of mercury at 500° C. to 600 mm. mercury at 925° C. The melting point of lead chloride is determined as 495° C. and the boiling point at 945° C. at a pressure of 754 mm. of mercury. The heat of vaporization of lead chloride at the melting point is calculated to be 40,600 calories. The vapor pressure of solid lead chloride, down to 400° C. are calculated and shown graphically. Details of the methods used and results obtained are given in the publication referred to above.

## AN ANALYTICAL METHOD FOR DETECTING BLOWN-OUT SHOTS IN COAL MINES.

**By G. F. Hutchison and Jacob Barab.**

A blown-out shot is the term applied to the detonation of a charge of explosive, intended to break down coal, or other mineral, when the explosion takes place much as it would in a gun-barrel, without causing much rupture of the material surrounding the charge. In investigating a coal-mine explosion, it is often desirable to ascertain whether a blown-out shot occurred, and, if so, what was the nature of the explosive used. It was determined by experiment that if the loose material within or about the collar of the hole is removed, the hole sampled, and scraped throughout its entire length, this material combined into a sample totaling at least half a pound, and the sample analyzed qualitatively and quantitatively, both the fact of an explosive having been fired in the hole, and also the general character of the explosive could be determined by comparing the results of the analysis with the analysis of coal taken from the same seam at a point as close as practicable to the hole. It is not, of course, possible to dis-

tinguish between explosives of similar composition, but as only a few kinds of explosives are usually used in an individual mine, it is usually practicable to distinguish between them. The method is not an exact one, but affords welcome aid in determining the causes of a mine explosion. Details of the method used are given in Technical Paper 210, U. S. Bureau of Mines.

## MINOR NOTES.

The Bureau of Mines is coöperating with Denver University in research on radium emanation and to date about 30 of the principal spectral lines of radium emanation have been established with certainty. About 20 of these lines coincide with the principal lines observed by other authorities, and the remainder seem to be new. Further work will be done to ascertain whether the large number of lines found by Rutherford all belong to the radium emanation spectrum.

At the Denver station of the Bureau two successful methods have been developed for the determination of copper in the presence of molybdenum. Three methods for the determination of molybdic acid in the presence of molybdenite were tried with successful results.

Studies at the Pittsburgh station upon the effect of solutions containing chromates upon the corrosion of steel, copper, and cupro-nickel indicate that it is possible to make steel passive without preventing the corrosion of copper and cupro-nickel in ammonia solutions.

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**California 220,000-volt, 1100-mile, 1,500,000-kw. Transmission Bus.** R. W. Sorenson. (*Proc. Am. Inst. Elec. Engs.*, September, 1919.)—In California small developments now produce a total of 325,000 kw. Four large projects can be developed to give 1,500,000 kw. within a few years.

For five years transmission has been successful in the southern part of the state at 150,000 volts. To distribute the output of the four plants the author suggests a two-circuit transmission system from Pit River in the north to Los Angeles with branch lines, 60 cycles, 220,000 volts. Thus all the power stations of the state would be linked together.

G. F. S.

**Mechanical Lifting Devices.** DANA WEBSTER. (*National Safety Council,* 1919.)—Lifting devices were undoubtedly used by Julius Cæsar, as far back as 265 B.C., as history mentions their lifting animals from the dens in the arena in the Coliseum of Rome. About the middle of the nineteenth century platforms or cable-hoisted elevators were first installed in New York and Boston, but were not provided with any kind of safety devices, and strange to say, you can find a few elevators without safety devices at the present time.

A few years later elevators were equipped with safety devices of such type that it was necessary for the hoist cable to break before the safety could actuate. There are a great many of this type of safety in use to-day, but with the introduction of high-speed elevators which are required to meet the demands of the public, quite naturally it necessitated much better type of safety apparatus and a multiplicity of cables.

Accidents could and did occur from over-speeding elevators caused by disarrangements of the controlling apparatus, and it became necessary to provide safety devices that would actuate should the elevator speed increase beyond a predetermined number of feet per minute.

The most essential elements of safety are the prevention of excessive speed from any cause, the over-running of the limits of travel at top and bottom, safe protection at the landing entrances to the elevator, and a regular examination of the cables and all parts of the elevator equipments. A. R.

**Aerial Fire Patrol.** (*Weekly News Letter, U. S. Department of Agriculture,* vol. vii, No. 6, p. 8, September 10, 1919.)—The airplane forest fire patrol conducted in the National Forests in California by the Army Air Service in coöperation with the Forest Service of the United States Department of Agriculture has been extended to cover a portion of the forests in Oregon. Headquarters have been established at Salem, Ore., and the operating squadron for the present will consist of five officers and seven enlisted men operating eight airplanes. The city of Portland has donated a landing field and will construct a hangar. Patrol routes in the Oregon and Santiam Forests are now being worked out.

One of the Army aviators in the fire-patrol work recently made a successful flight to the floor of the Yosemite Valley. To make a landing the aviator had to gain an altitude of 11,000 feet and spiral down between the walls of the canyon, which are 5000 feet high and a quarter of a mile apart. The landing was difficult because of high trees and wires. This exploit was of much interest to forest officers, as it is thought to have been a step toward the more extended use of airplanes in the forests, where landing places in the mountains are comparatively few.

A. R.

# THE FRANKLIN INSTITUTE.

(*Proceedings of the Stated Meeting Held Wednesday, November 19, 1919.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 19, 1919.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to the membership since last report, 9.

The following gentlemen nominated by the Board of Managers for Corresponding Membership were unanimously elected:

Dr. A. S. Eve, Professor of Physics, McGill University, Montreal; Dr. John S. Townsend, Professor of Physics, Oxford University; Professor Charles Fabry, Professor of Physics, University of Marseilles.

Reports of progress were presented by the Committee on Library, and the Committee on Science and the Arts.

The Chairman then announced that the next business of the Meeting would be the presentation of the medals and certificates to the gentlemen whose inventions had been examined, by the Committee on Science and the Arts, and found worthy of recognition by the Institute.

Mr. Benjamin Franklin, Chairman of the Committee on Science and the Arts, then introduced Mr. Harvey D. Williams and Mr. Reynold Janney, who had been recommended jointly for the award of the Potts Medal, for their inventions embodied in what is known as the "Waterbury Hydraulic Speed Gear." The President then presented the medals and certificates to Messrs. Williams and Janney.

Mr. Clarence P. Landreth, of Philadelphia, whose "Electrolytic Sewage Process" had also been recommended for the award of the Potts Medal, was next introduced, and the medal and accompanying certificate were presented to him by the President.

Mr. Franklin was again recognized, and described the invention in the art of radiography, made by Mr. H. Clyde Snook, of New York City. Mr. Snook was recommended for the award of the Edward Longstreth Medal of Merit, and this with the accompanying certificate was presented to him by the President.

Rear Admiral J. A. Hoogewerff, U. S. N., Superintendent of the U. S. Naval Observatory, Washington, D. C., then presented the paper of the evening, entitled "The Relation of the U. S. Naval Observatory to the Navy and Shipping Interests of the Country." The speaker referred to the dependence of the sailor on the practical applications of astronomy, and gave an account of the work of the U. S. Naval Observatory. After reviewing, briefly, the history of the Observatory, he described its various activities, including its time service, the publication of the American Ephemeris and Nau-

tical Almanac, its work in connection with navigational instruments, and its library. The war-time activities of the Naval Observatory were also reviewed. The subject was illustrated by lantern slides. After a brief discussion, the thanks of the Meeting were extended to the speaker.

Adjourned.

R. B. OWENS,
*Secretary.*

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## COMMITTEE ON SCIENCE AND THE ARTS.

*(Abstract of Proceedings of the Stated Meeting held Wednesday, November 5, 1919.)*

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 5, 1919.

MR. BENJAMIN FRANKLIN *in the Chair.*

The following report was presented for first reading:

No. 2713: Kemp Gas System.

A report was presented by the Special Committee on the Louis Edward Levy Memorial.

R. B. OWENS,
*Secretary.*

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## SECTIONS.

*Section of Physics and Chemistry.*—A meeting of the Section was held in the Hall of the Institute on Thursday evening, October 23, 1919, at 8 o'clock, with Dr. George S. Crampton in the Chair. The minutes of the previous meeting were approved as published.

Augustus Trowbridge, Ph.D., D.S.M., D.S.O., Chev.L.H., Professor of Physics in Princeton University, and late Lieutenant Colonel of Engineers, attached to the General Staff and in technical charge of Sound and Flash Ranging in the American Expeditionary Force, delivered an illustrated lecture on "Flash and Sound Ranging Apparatus for the Location of Guns." The development of modern methods for locating the position of enemy artillery, and directing the fire of friendly artillery was traced. A description was given of the principles of both flash and sound ranging, the methods and apparatus used by the ranging troops of the American Expeditionary Force in France, and the quality and quantity of the information thus obtained. The paper was discussed; a vote of thanks was extended to Doctor Trowbridge, and the meeting adjourned.

JOSEPH S. HEPBURN,
*Secretary.*

*Electrical Section.*—A joint meeting of the Section and the Philadelphia Section American Institute of Electrical Engineers was held in the Hall of the Institute on Thursday evening, October 30, 1919, Mr. W. C. L.

Eglin and Prof. C. E. Clewell presiding jointly. The paper of the evening on "Wireless Telephony" was presented by Mr. N. H. Slaughter, of the Engineering Department, Western Electric Company, New York City, and formerly Lieutenant Colonel Signal Corps, U. S. A. The speaker reviewed briefly the pre-war development of radio telephony, and gave a summary of its war-time development and application. The Airplane Radio Telegraph Set used by the Army was described in detail and was illustrated by lantern slides and specimens of apparatus. An outline of the future uses and possibilities of Radio Telephony in military and commercial fields was also given, as well as its applications in aviation. After a brief discussion the thanks of the meeting were conveyed to the speaker.

R. B. Owens,
*Secretary.*

*Section of Physics and Chemistry.*—A joint meeting of the Section with the Philadelphia Section of the American Chemical Society was held in the Hall of the Institute on Thursday evening, November 6, 1919, at 8 o'clock. Dr. Harry F. Keller, on behalf of the Section, and Mr. Samuel S. Sadtler, on behalf of the American Chemical Society, presided jointly. The minutes of the previous meeting were read and approved.

Bernhard C. Hesse, Ph.D., of New York City, presented a communication on "American Dye Industries—Present and Future." The world position of this industry in 1913 and at the present time were contrasted. The competitive conditions of the present and those to be expected in the near future were summarized. An outline was given of the protective legislation required to insure in this country a self-contained and self-sustaining coal-tar chemical industry in all its more important ramifications.

The paper was discussed. On motion of Dr. Walton Clark, a vote of thanks was extended to Doctor Hesse. The meeting then adjourned.

Joseph S. Hepburn,
*Secretary.*

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## MEMBERSHIP NOTES.

### ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, November 12, 1919.*)

RESIDENT.

Mr. George W. Birch, Chemist, 1414 Columbia Avenue, Philadelphia, Pennsylvania.

Mr. Frank H. Griffin, Chief Chemist, The Viscose Company, Marcus Hook, Pennsylvania.

Mr. Edward F. Henson, Lumber Merchant, 921 North Delaware Avenue, Philadelphia, Pennsylvania.

Mr. Hosford D. Kellogg, Manager, The H. B. Smith Company, 17th and Arch Streets, Philadelphia, Pennsylvania.

MR. FRANK G. KENNEDY, JR., President, Logan Iron and Steel Company, 1218 Stephen Girard Building, Philadelphia, Pennsylvania.

MR. W. LEIGH SMITH, Chemist, The Viscose Company, and for mail, Box 171, Marcus Hook, Pennsylvania.

NON-RESIDENT.

DR. ROBERT R. TATNALL, Research Engineer, J. E. Rhoads & Sons, Wilmington, Delaware.

ASSOCIATE

MR. JUDSON T. BALLARD, Chemist, 6416 North 11th Street, Oak Lane, Philadelphia, Pennsylvania.

MR. KENNETH BRADDOCK-ROGERS, Haverford College, Haverford, Pennsylvania.

## CHANGES OF ADDRESS.

MR. HENRY B. ALLEN, 8112 St. Martins Lane, Chestnut Hill, Philadelphia, Pennsylvania.

MR. J. EDWARD BARNHART, 407 Waldo Avenue, Pasadena, California.

MR. M. C. BURT, in care of Aetna Explosives Company, 165 Broadway, New York City, New York.

MR. CLARENCE R. CLAGHORN, in care of Vinton Colliery Company, 50 East 42nd Street, New York City, New York.

LIEUT.-COL. EDWARD B. CLARK, 61 Cedar Street, Chicago, Illinois.

MR. H. V. COES, in care of Ford, Bacon & Davis, 115 Broadway, New York City, New York.

DR. THOMAS D. COPE, Randal Morgan Laboratory of Physics, University of Pennsylvania, Philadelphia, Pennsylvania.

MR. ELLIOTT CURTISS, 429 North 13th Street, Philadelphia, Pennsylvania.

MR. S. B. ECKERT, Finance Building, 1428 South Penn Square, Philadelphia, Pennsylvania.

MR. E. W. FINKBINER, 207 Market Street, Newark, New Jersey

MR. W. E. FLETCHER, in care of Atlas Powder Company, 140 North Broad Street, Philadelphia, Pennsylvania.

MR. FRANK B. GILBRETH, 68 Eagle Rock Way, Montclair, New Jersey.

MR. MARTIN L. GRIFFIN, Mount Hope Finishing Company, North Dighton, Massachusetts.

MR. TABER HAMILTON, 1335 West Main Street, Louisville, Kentucky.

MR. GEORGE R. HENDERSON, The Aldine Hotel, 1920 Chestnut Street, Philadelphia, Pennsylvania.

MR. ROBERT E. HORTON, R. F. D. No. 1, Voorheesville, New York.

MISS EMILY E. HOWSON, 306 Woodlawn Road, Roland Park, Maryland.

COL. P. JUNKERSFELD, Stone & Webster Engineering Corporation, 147 Milk Street, Boston, Massachusetts.

MR. J. BENTON PORTER, General Electric Company, Equitable Building, 120 Broadway, New York City, New York.

MR. JANVIER RESINES, Racquet Club, Philadelphia, Pennsylvania.

MR. CHARLES E. RILLIET, in care of Washburn Continuation School, 655 West 14th Street, Chicago, Illinois.

Mr. Edmund G. Robinson, 909 Nottingham Road, Wilmington, Delaware.
Mr. J. B. Rumbough, P. O. Box No. 2, Asheville, North Carolina.
Mr. Frederick W. Salmon, 1129 North 28th Street, Birmingham, Alabama.
Mr. A. B. Stitzer, in care of Republic Engineers, Inc., 60 Broadway, New York City, New York.
Mr. John Stone Stone, New Palace Hotel, San Diego, California.
Dr. Paul Strauss, 1030 Beverly Road, Brooklyn, New York.
Mr. F. M. Tait, 80 Broadway, New York City, New York.
Mr. Paul Thompson, N. W. Cor. Broad and Arch Streets, Philadelphia, Pennsylvania.
Mr. B. C. Tilghman, Highfield, Dunham Road, Altrincham, Cheshire, England.
Mr. C. C. Tutwiler, West Conshohocken, Pennsylvania.
Mr. Carl D. Ulmer, 1807 Fourth Street, S. E., Minneapolis, Minnesota.
Mr. J. Valasek, 1117 Seventh Street, S. E., Minneapolis, Minnesota.
Mr. F. R. Wadleigh, in care of Weston, Dodson & Company, Inc., 17 Battery Place, New York City, New York.
Mr. Percy Wedlake, 125 Atlantic Street, S. E., Washington, D. C.
Mr. H. A. Wilson, Coronado Apartments, 22nd and Chestnut Streets, Philadelphia, Pennsylvania.
Mr. H. D. Wilson, Coronado Apartments, 22nd and Chestnut Streets, Philadelphia, Pennsylvania.
Mr. Roy V. Wright, 398 North Walnut Street, East Orange, New Jersey.

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## LIBRARY NOTES.

### PURCHASES.

Business Digest, July–December, 1918. Vol. vi.
Card, S. F.—Air Navigation, Notes and Examples. 1919.
Collins, S. H.—Plant Products, and Chemical Fertilizers. 1919.
Humphreys, A. C.—Lecture Notes on Some of the Business Features of Engineering Practice. 1916.
International Catalogue of Scientific Literature, vol. xiv. F—Meteorology, J—Geography. 1919.
Johnson, J. B.—Materials of Construction; Rewritten by M. O. Withey, and James Aston. 1918.
Lindgren, Waldemar.—Mineral Deposits. 1919.
Reader's Guide to Periodical Literature, vol. iv. 1915–1918.
Rideal, E. K.—Industrial Electrometallurgy. 1919.
Schoeller, W. R., and Powell, A. R.—Analysis of Minerals and Ores of the Rarer Elements. 1919.
Seidel, Atherton.—Solubilities of Inorganic and Organic Compounds. 1919.
Sibley, R., and Delany, C. H.—Elements of Fuel Oil and Steam Engineering. 1918.
Steinheil, Adolph, and Voit, E.—Applied Optics, vol. ii. 1919.

GIFTS.

Adams-Bagnall Electric Company, Catalogue of Abolites. Cleveland, Ohio, 1919. (From the Company.)

Allen Cone Company, Bulletin No. 5. El Paso, Texas, 1919. (From the Company.)

American Blower Company, Bulletin No. 19. Detroit, Mich., 1919. (From the Company.)

American Society for Testing Materials, Membership List. Philadelphia, Pa., 1919. (From the Society.)

L'Année Scientifique et Industrielle, 1908. Paris, 1909. (From Mr. W. G. Button.)

Appleton Electric Company, Catalogue No. 8. Chicago, Ill, 1918. (From the Company.)

Badger, E. B., and Sons Company, Bulletin No. 100. Boston, Mass., 1919. (From the Company.)

Bausch and Lomb Optical Company, Catalogue of Optical Glass. Rochester, N. Y., 1919. (From the Company.)

Canada Department of Mines Summary Report, 1918, Parts C, D, F, G. Ottawa, Canada, 1919. (From the Department.)

Channon H. Company, Catalogue No. 80. Chicago, Ill., 1916. (From the Company.)

Chemie der menschlichen Nahrungs-und Genussmittel. By Dr. J. Koenig, two vols. Berlin, Germany, 1879–1880. (From Mr. Reuben Haines.)

Clayton and Lambert Manufacturing Company, Bulletin No. 4. Detroit, Mich, no date. (From the Company.)

Clow, James B., and Sons, Booklet of Water Sterilization. Chicago, Ill., 1919. (From the Company.)

Colonial Steel Company, Colonial Steel Treating Book. Pittsburgh, Pa., 1919. (From the Company.)

Colorado Bureau of Mines, Bulletin No. 8. Denver, Col., 1919. (From the Bureau.)

Columbia University, Publication No. 8. New York, N. Y., 1919. (From the University.)

Condit Electrical Manufacturing Company, Catalogue No. 125. Boston, Mass., no date. (From the Company.)

Davis-Boutnonville Company, Catalogue of the Pyrograph. Jersey City, N. J., 1919. (From the Company.)

Economy Electric Devices Company, Bulletins Nos. 50 and 60. Chicago, Ill., no date. (From the Company.)

General Chemical Company, Bulletin No. 3. New York, N. Y., no date. (From the Company.)

George Washington University, Catalogue No. 2. Washington, D. C., 1919. (From the University.)

Gilfillan Brothers Smelting and Refining Company, Catalogue of Gilfillan Products. Los Angeles, Calif., 1919. (From the Company.)

Hamilton Association, Journal and Proceedings. Hamilton, Canada, 1919. (From the Association.)

Hendrie and Bolthoff Manufacturing and Supply Co., Catalogue No. 50. Denver, Col., 1919. (From the Company.)

Hornung, J. C., Bulletin No. 14. Chicago, Ill., 1919. (From J. C. Hornung.)

How the Nitrogen Problem Has Been Solved. By Henry Jermain Maude Creighton. Philadelphia, Pa., 1919. (From the Author.)

Instituo y Observatorio de Marina, Anales 1916–1917. San Fernando, 1917–1918. (From the Institute.)

Kansas Board of Agriculture, Report for the Quarter ending March, 1919. Topeka, Kan., 1919. (From the Board.)

Lehrbuch der Organischen Chemie. By Dr. E. F. v. Gorup-Besanez, three vols. Braunschweig, 1873–1874. (From Mr. Reuben Haines.)

Locke Insulator Manufacturing Company, The Insulator Book. Victor, N. Y., 1919. (From the Company.)

Los Angeles Pressed Brick Company, Catalogue of Roofing Tiles. Los Angeles, Calif., 1919. (From the Company.)

McCool Company, Bulletin No. 49. Cleveland, Ohio, 1919. (From the Company.)

McDonald, A. Y., Manufacturing Company, Catalogue No. 5. Dubuque, Iowa, no date. (From the Company.)

Manufacturers' Aircraft Association, Year-Book, 1919. New York, N. Y., 1919. (From the Association.)

Massachusetts Board of Gas and Electric Light Commissioners, Thirty-fourth Annual Report, 1918. Boston, 1919. (From the Board.)

Massachusetts Oilless Bearings Company, Catalogue of Oilless Bearings. Worcester, Mass., no date. (From the Company.)

Merchants Association of New York, Year-Book, 1919. New York, N. Y., 1919. (From the Association.)

Michigan College of Mines, Year-Book, 1918–1919. Houghton, Mich., 1919. (From the College.)

Millers Falls Company, Hack Saw Efficiency. Millers Falls, Mass., 1919. (From the Company.)

Monighan Machine Company, Catalogue No. 19. Chicago, Ill., 1919. (From the Company.)

Nelson Valve Company, Catalogue No. 10. Philadelphia, Pa., 1919. (From the Company.)

New York City Board of Water Supply, Thirteenth Annual Report, 1919. New York, 1919. (From the Board.)

North Western Expanded Metal Company, Handbook of Fire-proof Construction. Chicago, Ill., no date. (From the Company.)

Ohio Blower Company, Catalogue No. 22. Cleveland, Ohio, 1919. (From the Company.)

Ohio Brass Company, Catalogue No. 17. Mansfield, Ohio, 1919. (From the Company.)

Ohio University, Catalogue 1918–1919. Columbus, Ohio, 1919. (From the University.)

O. K. Clutch and Machinery Company, Catalogue No. 19. Columbia, Pa., no date. (From the Company.)

Ontario Hydro-electric Power Commission, Eleventh Annual Report, 1918. Toronto, 1919. (From the Commission.)

Owen Bucket Company, Catalogue of Owen Buckets. Cleveland, Ohio, 1919. (From the Company.)

Smithsonian Institution, Publication No. 2493. Washington, D. C., 1918. (From the Institution.)

South Dakota Board of Railroad Commissioners, Twenty-ninth Annual Report for 1918. Pierre, South Dakota, 1919. (From the Board.)

Southern Railway Company, Twenty-fifth Annual Report, 1918. Richmond, Va., 1919. (From the Company.)

St. Louis Water Commissioner, Annual Report for Year ending April 1, 1919. St. Louis, Mo., 1919. (From the Commissioner.)

Stimpson Equipment Company, Catalogue of the Mitchell Electric Vibrating Machine. Salt Lake City, Utah, no date. (From the Company.)

Stow Manufacturing Company, Inc., Bulletin No. 103. Binghamton, N. Y., 1919. (From the Company.)

Strong, Carlisle and Hammond Company, Catalogue of Strong Steam Specialties. Cleveland, Ohio, no date. (From the Company.)

Sturtevant, B. F., Company, Catalogue No. 255. Hyde Park, Mass., 1919. (From the Company.)

Superheater and Engineering Company, Catalogue of Dravo Superheaters. New York City, N. Y., 1919. (From the Company.)

Tasmania Geological Survey, Bulletin No. 29. Hobart, 1919. (From the Survey.)

Thacher Propeller and Foundry Corporation, Catalogue M. Albany, N. Y., 1919. (From the Company.)

University of Missouri, Bulletin No. 3. Rolla, Mo., 1918. (From the University.)

Watuppa Water Board, Forty-fifth Annual Report. Fall River, Mass., 1919. (From the Board.)

Wellman-Seaver-Morgan Company, Bulletin No. 34. Cleveland, Ohio, 1919. (From the Company.)

Weston Electrical Instrument Company, Bulletin 20-A. Newark, N. J., 1919. (From the Company.)

Wetzel Mechanical Stoker Company, Catalogue No. 9. Trenton, N. J., 1919. (From the Company.)

## PUBLICATIONS RECEIVED.

*The Analysis of Minerals and Ores of the Rarer Elements for Analytical Chemists, Metallurgists and Advanced Students:* By W. R. Schoeller, Ph. D., and A. R. Powell. 239 pages, 8vo. London, Chas. Griffin & Co.; Philadelphia, J. B. Lippincott Company, 1919, price $5.

*U. S. Bureau of Mines:* Monthly Statement of Coal-Mine Fatalities in the United States, August, 1919, compiled by Albert H. Fay. 20 pages, 8vo. Technical Paper 210. An Analytical Method for Detecting Blown-out Shots in Coal Mines, by G. F. Hutchison and Jacob Barab. 22 pages, 8vo. Technical Paper 231. Production of Explosives in the United States During the Calendar Year 1918, compiled by Albert H. Fay. 21 pages, 8vo. Technical Paper 234. Sensitiveness of Explosives to Frictional Impact, by S. P. Howell. 17 pages, 8vo. Technical Paper 236. Abatement of Corrosion in Central

Heating Systems, by F. N. Speller. 12 pages, 8vo. Technical Paper 237. Safe Practice in Using Wire Ropes in Mines, by R. H. Kudlich and O. P. Hood. 11 pages, 8vo. Technical Paper 242. Why and How Coke Should be Used for Domestic Heating, by Henry Kreisinger and A. C. Freedner. 20 pages, 8vo. Washington, Government Printing Office, 1919.

*Library News:* Semi-Monthly Bulletin of the Engineer School Library issued at Camp A. A. Humphreys, Va. Vol II, Nos. 11–14, June and July, 1919. 8vo.

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Melting Point of Refractory Materials. LEO I. DANA. (*Bull. Am. Inst. Mining and Metallurgical Engineers,* September, 1919.)—As refractory substances are usually not pure crystalline materials, their change from the solid to the liquid state is not sharply marked as in the case of ice, but is a gradual process, and extends through a range of temperature. Sintering or vitrification is the first stage on the road to liquefaction. Circumstances which affect the apparent melting point are:

(*a*) Time during which the refractory is kept at a temperature producing vitrifaction. The longer the time the more complete is the sintering and other physical and chemical results. Lengthening the time increases fusibility.

(*b*) Rate of heating. In general the more rapidly the temperature rises the higher the melting point seems to be.

(*c*) Nature of surrounding atmosphere. This may enter into chemical combination with the refractory substance or may influence volatilization.

(*d*) Substances in contact with the refractory, such as slags, fluxes and flue dust.

(*e*) The load applied.

The influence of these last factors is so complex that at present it is impossible in general to predict what effect will be produced on the melting point by varying them.

G. F. S.

Spraying Metals. (*Electrician,* vol. lxxxiii, September 19, 1919, p. 302.)—Schoop's process of spraying metals is being further developed. Two wires of the metal are connected to the terminals of the electric circuit, then touched and separated to form an arc. This fuses part of the wires which are fed forward continuously. An air blast projects the molten metal in finely divided form upon any desired object. Glass, celluloid, paper, etc., are thus given a metallic coating. Glass plates so prepared are used for electrical condensers. The process is employed also to secure good metallic contact, and to facilitate soldering. Electric heaters are made by spraying metal on refractory substances.

G. F. S.

# CURRENT TOPICS.

**Optical Glass and Chemical Glassware.** (*U. S. Tariff Commission Information Bulletin*).—Of the many industries that have been developed in this country by the necessities of the war, few, if any, have had such brilliant success as the manufacture of glass for scientific purposes. The lack of supply for these purposes began to be felt as soon as the British blockade became effective, and by 1917 the attention of American scientists and officials had been strongly directed to the problem of home manufacture. Optical glass has for many years been imported, principally from Germany, but some from France and England. It was not made in the United States. Rough or unwrought optical glass has been for years on the free list. At the present time through the large experience and organization developed by the necessities of the case, the optical glass industry in the United States has the scientific knowledge, materials, and equipment to compete in regard to quality of product with the best of foreign manufacture. Still the whole demands of the market are not met, for in 1918 we were obliged to import about one-half the normal amounts of unwrought glass and in addition large amounts in the form of optical instruments. Scientific authority informs us that four kinds of optical glass are the most needed: A very light and transparent crown, an ordinary crown of higher index, a typical heavy flint and a typical light flint. Next to these most important forms, are a heavy barium crown and a light barium flint especially used in photographic apparatus. The further development of these industries cannot be expected if such products are kept on the free list or subjected to merely nominal duties, and moreover, the present condition by which all educational institutions are permitted to import even complete optical instruments free of duty, will seriously interfere. Glass makers are asking for the repeal of this clause, a request which has met with a good deal of approval from the scientific workers of the country.

Chemical glassware, generally known in the trade as "hollow ware" is used in enormous amounts in the United States, and has been for many years almost entirely supplied by Germany and Austria, the several brands being among the most familiar titles in the laboratory. This supply also being shut off, the attention of American glass-makers was directed to finding substitutes, and here, as in the case of the optical glass, great success has been achieved. Indeed, it is now generally admitted that much of the American glass is better than any that has heretofore been

obtainable from abroad. Factory-blown ware of this high quality is now being made in seven American factories that were in active operation for ordinary glass-making before the war. These manufacturers express confidence that they can maintain their industries without increase of the present duty of 45 per cent. ad valorem, but ask that the duty-free clause applicable to scientific institutions which are very large users of these forms of glass-ware owing to the students laboratories, be repealed and that all chemical glass-ware be made dutiable at the 45 per cent. rate. Here again, the expressions of chemists and officers of scientific institutions are largely favorable to the repeal. Statistics show that before the war the duty free importations amounted to about half of the value of the total imports based on the invoices.

The Bureau of Standards has made thorough examinations of the American ware in comparison with the best foreign ware, and reports that all the former are superior to the Kavalier ware and equal or superior to the Jena ware for general laboratory use.

H. L.

**Utilization of Nitre-Cake.** GILBERT T. MORGAN. (*Economic Proceedings, Royal Dublin Society,* vol. ii, p. 238, 1919.)—Nitre-cake is the residue of the action of sulphuric acid upon sodium nitrate, and consists mainly of sodium acid sulphate. During the war British munition industries produced enormous quantities of this material, one factory alone having an output of over 200 tons per week, much of which was dumped into the sea. When the output was much smaller, as in peace-times, the material was utilized for the manufacture of salt-cake and hydrochloric acid, the former being employed in the Leblanc process for sodium carbonate. Some of the nitre-cake was converted into sodium sulphide, which is now used as a reducing agent in organic syntheses.

Morgan sought for some methods which would utilize the sulphur as well as the sodium. He reviews the methods already known, and then describes a procedure devised by himself in which the cake is used for the production of soda-lime and soda-lead glasses at one operation with recovery of the sulphur, either free or as sulphuric acid. It will suffice to describe briefly one of these procedures.

Seventy-two grammes of nitre-cake, 100 grammes of sand, 20 grammes of limestone, and 4 grammes of wood charcoal, were heated in a fire-clay retort connected with a model of a leaden chamber. The fixed product was clear green glass, the volatile products were sulphuric acid, sulphur dioxide, and free sulphur. The heating was continued for twelve hours, but the bulk of the volatile products was evolved in the first two hours. The volatile products were then mixed with steam, air, and nitrous fumes for oxidation. The analytical figures show that over half the sulphur can be recovered either as sulphuric acid or as the free element.

H. L.

**Water Power of France.** (*Bull. Am. Inst. Mining and Metallurgical Engineers,* September, 1919.)—In the Alpine region drained by the Rhone and its tributaries 6,000,000 horsepower can be developed at average water flow. Elsewhere in France 3,000,000 horsepower additional may be obtained from streams. These numbers should be divided by two to get the output for low-water flow. At the close of 1915, 738,000 horsepower was obtainable from installations in the Alps. This amount has been much increased since that time. G. F. S.

**Depreciation in Small Dry Cells with Age.** A. J. HELFRECHT. (*American Electrochemical Society,* 1919.)—The author endeavors to show how closely the method of judging cell deterioration, called "flash test," approaches actual measurements of capacity through discharging the cells. Comparative curves for the different sizes of cells tested are given. From the data gained by this investigation a table has been compiled indicating reasonable depreciation of the four important sizes of small cells.

**The Effect of Amalgamation Upon the Single Potential of Aluminum.** LOUIS KAHLENBERG and JOHN A. MONTGOMERY. (*American Electrochemical Society,* 1919.)—Measuring the single potential of aluminum in a one-third molar solution of aluminum chloride at room temperature, by means of the calomel electrode, the writers obtained much higher values with amalgamated than with unamalgamated aluminum, due to the removal of the coat of resistant oxide by the mercury. They showed also that the measurements were actually the single potentials of the aluminum and not those of an aluminum amalgam.

**Invisible Light in Warfare.** R. W. WOOD. (*Proceedings of the Physical Society of London,* vol. xxxi, p. 232, 1919.)—When a source of light is put at the principal focus of a converging lens the emergent beam consists of parallel rays and consequently does not change in cross-section as it proceeds. Often the narrowness of such a beam prevents its being observed. Greater accuracy was obtained by using a filter which permitted only the extreme red rays to issue. These would be invisible to an observer unless he protected his eyes from daylight by a similar screen. Through such a screen only the red light could penetrate and the eyes of the observer would be in a sensitive state owing to the exclusion of ordinary light. By such an arrangement secret signals can be transmitted. A variation of method was the use of a screen transmitting only ultra-violet light, which was received on a fluorescent screen. The range of signalling in both cases was about six miles.

The following arrangement proved of great value in maintaining communication between ships of the same convoy at night. In this case the light was sent out not as a parallel beam, but as a

beam diverging in all directions. A Cooper-Hewitt mercury arc was the light source. It was surrounded by a glass chimney through which only ultra-violet light emerged. This caused parts of the eye and natural teeth to fluoresce, while false teeth were black. The receiving apparatus is a barium-platino-cyanide screen placed in the principal focus of a converging lens. The range was about four miles. G. F. S.

**Location of Aeroplanes by Wireless Telegraphy.** J. ROBINSON. (*Nature,* September 11, 1919.)—Dead reckoning methods are of little use for such a purpose owing to the pilot's ignorance of the velocity of the air with respect to the earth. A loop of wire exposed to electrical waves has an E.M.F. developed in it which varies in strength according to the relation of the plane of the loop to the direction in which the waves are travelling. By changing this spatial relation and by noting the effect upon the current induced in the loop it is possible to find the location of the aeroplane. The Germans did this by sending waves out from the aircraft and by receiving them on loops at various places on the ground. Observers at a central station worked out the position of the source of the waves and sent the information to the aeroplane.

The Royal Air Force solved the problem by having a loop on the aeroplane receive waves from several stations. The bearing of each station was worked out by the aerial observer and from this he worked out his position. As wireless signals are noted by the ear, difficulty was found in applying this method owing to the noises of the wind and of the engine. This obstacle was overcome by increasing the strength of the signals. Electrical disturbances emanating from the magneto were avoided by shielding the machine.

Two loops, main and auxiliary, with planes at right angles to each other were mounted on the aeroplane. When the loops have this relative position one has its maximum current when the other has its minimum. Suppose the main loop is turned until its current is a maximum and that then the auxiliary loop is joined to the main one. A little later the auxiliary loop is joined in the reversed direction. As this loop had no current, reversing it makes no difference. If, however, the main loop was not accurately in the position for maximum current, the auxiliary loop would have a current in it and reversing it would make a difference. The procedure is to rotate the main loop until its position for maximum current is approximately found. Then the auxiliary coil, always at right angles to the other, is introduced into the circuit first in one direction and then in the other, and the two loops are rotated about their common axis until no change in the intensity of the signals is caused by reversing the auxiliary loop. Then the position of the plane of the main loop to the direction of propagation of the waves is known.

The two loops may be mounted on the framework of the aeroplane, in which case the whole plane must be swung to vary their direction, or they may be supported by a mounting attached to the fuselage so that they may be turned independently of the plane.

The German method of calculation performed on the ground is the more accurate, since it gives the position of the aeroplane within two miles, while the other method, largely owing to compass errors, has an error of seven miles. Nevertheless, long flights have been made by the use of the latter method, *e.g.*, from a town near London to Paris and back to England. The navigator was able to forecast the time of his arrival within two minutes.

G. F. S.

**The British Fleet During the War.** SIR E. T. D'EYNCOURT, K.C.B. (*Institution of Naval Architects,* April 7, 1919, through *Journal of the American Society of Naval Engineers,* May, 1919.)—During the war the additions to the British fleet amounted to 2,000,000 tons at a cost of £250,000,000. Great efforts were made to finish the vessels already under way. Only such others were ordered as could be designed and completed in a short time. Belief in a brief war modified the naval program. As soon as the submarine menace was recognized, orders were placed for patrol boats, torpedo-boat destroyers, submarines, light cruisers, sloops, mine sweepers, etc. Many such were satisfactorily constructed by firms hitherto engaged only in commercial work.

The experience acquired in the battle of Jutland led to the application of additional protection to the magazines of battleships. The value of the longitudinal, protective bulkhead with the accompanying subdivisions was demonstrated when the post-dreadnaught *Marlborough* was torpedoed and yet was able to keep in line. She was safely docked in the Tyne. The decision to increase the speed of the battleships of the Queen Elizabeth class from 21 to 25 knots necessitated the doubling of the horsepower. This class had oil as the sole fuel with oil bunkers 30 feet high, especially designed to withstand the pressure of the contained liquid. Oil fuel was a distinct success as it was found easier to maintain a high speed continuously by its use. Of course, a smaller number of men were needed than with coal.

The shaft horsepower of the battle-cruisers reached 112,000 in the case of the *Renown* class with a displacement of 26,500 tons and speed of almost 32 knots. Two vessels of this classs had their commissioning trials a trifle more than eighteen months after the date of the first order to get out their design.

Three hundred torpedo-boat destroyers and flotilla leaders as well as 100 mine sweepers were added to the British fleet. "China" gunboats, 120 feet long, were constructed in Great Britain and sent out in parts to be assembled at Abadan. Twelve types of submarines were made, among which was one employing steam tur-

bines for the surface, by which a speed of 24 knots was obtained. The problem of caring for the funnels was successfully solved. These vessels had electric drive while under water, and a Diesel engine to use in the act of submerging or of emerging. The claim is made that the British produced submarines with greater speed on the surface and also under water than the Huns had, as well as more heavily armored craft. One monitor submarine carried a twelve-inch gun.

Among auxiliary craft are fast fleet oilers, carrying 5000 tons of oil, speed 15 knots. Aircraft carriers were made from merchant ships. Of these the *Argus* had flush decks and long horizontal ducts to discharge the smoke astern. G. F. S.

**Potash from Kelp.** J. W. TURRENTINE and PAUL S. SHOAFF describe the experimental plant of the U. S. Department of Agriculture at Summerland, California. (*Journal of Industrial and Engineering Chemistry*, vol. xi, pp. 864–874, 1919.)—Kelp is collected by boats of 100 to 150 tons capacity, provided with twin screws and driven by internal combustion engines. The extreme bow of the boat is provided with the harvesting apparatus, the kelp is cut by means of knives approximately four feet below the surface of the water, and is then carried to the deck by a conveyor, from 25 to 50 tons are harvested in an hour. The cargo is removed from the boat by an automatic fork which delivers its load to the hopper of a chopper on the dock. The chopper cuts the kelp into lengths of approximately 6 feet, which are then moved to the storage bin of the plant by drag conveyors. The raw kelp is fed into a rotary drying kiln, where it meets a counter current of hot air, which enters the kiln at a temperature of 800° C. and leaves it at a temperature of 50° C. This preliminary drying is followed by a final drying in a similar kiln. The dried kelp is fed into the top of a retort, which is kept at a temperature of approximately 980° C. The charred mass is drawn off from a hopper at the bottom of a retort, cooled, ground and lixiviated. The by-products are recovered.

In the lixiviation use is made of leaching troughs, filter presses, and the principle of the counter current. The char is first extracted with a concentrated brine, while fresh hot water is used for its final extraction. The press coke of charcoal is extracted successively with hot hydrochloric acid and water, by proper extraction, a product is obtained which is of value as a decolorizing agent for certain organic liquids and aqueous solutions. The charcoal is then collected in a filter press and dried.

After removal of sulphates, the brine from the leaching process is heated in a vacuum pan until a definite concentration is reached, it is then transferred to a vacuum crystallizer, where the potassium chloride deposits. The cooled brine is returned to the vacuum pan and further concentrated while sodium chloride separates. Each salt is washed, dried first in a centrifugal ma-

chine, then in a rotary, counter-current, hot-air drier, and finally packed for market. The mother liquors are used until their content of iodine salts has become sufficiently great. They are then treated for the recovery of iodine as a by-product.

The volatile by-products recovered from retorting include ammonia liquor, methyl alcohol, and an oily distillate from which have been obtained an oil which is of value in the concentration of ores by flotation, and a creosote which is highly toxic to bacteria and may be used as a wood preservative. Gas is also produced in the retort and is used as fuel.

By another process, the dried kelp is fed into one end of a rotary kiln while a flame from burning oil enters at the other end; the kiln is lined with fire brick. Charcoal is produced and leaves the kiln at a low red heat; it may be quenched, ground, and leached to obtain the potash salts, or it may be permitted to burn to a loose, gray, non-caking kelp ash with a potassium content equal to approximately 35 per cent. $K_2O$.

**Manufacture of War Gases in Germany.** JAMES F. NORRIS. (*Journal of Industrial and Engineering Chemistry,* vol. xi, pp. 817–829.)—This paper by Lieutenant-Colonel Norris is based on his official tour of inspection of chemical plants at Leverkusen, Höchst am Main, Biebrich, and Ludwigshafen in the occupied zone of Germany. In addition to the manufacture of poison gases, attention is also paid to the manufacture of synthetic rubber and of charcoal for gas masks.

Rubber was manufactured from acetone. This compound was reduced to pinacone by means of aluminum and hydroxide. The pinacone was distilled under pressure; it thereby lost water from its molecule, and yielded a distillate of methyl butadiene, an unsaturated hydrocarbon. Polymerization was produced by heating this hydrocarbon at a temperature of approximately 600° C. for a period of 4 to 6 months; the product of methyl rubber was a clear, tough, white, transparent mass, with the properties of the best caoutchouc, and was used in the manufacture of automobile tires and other rubber goods.

Charcoal for gas masks was made from pieces of wood (usually pine) of even size and one-fourth inch in diameter. They were soaked for at least 30 minutes in hydrochloric acid of 20° to 40° Baume, to which a small, but indefinite amount of zinc chloride had been added. They were then packed into a muffle, which was 24 inches square by 12 feet long, until only a few inches of air space remained above the pile of wood. The muffle was provided with an iron door, a lining of porcelain tile and a stoneware flue pipe, which led to an hydrochloric acid condenser plant. Carbonization occurred slowly and very thoroughly; the muffle was heated to a cherry red, and heat was applied for at least 6 or 8 hours. The charcoal was washed with hydrochloric acid until the soluble

ash had been reduced to a minimum, and the finished product contained approximately 0.01 per cent. of zinc. It was next washed free from acid. The total time required for washing was 2 or 3 days. The charcoal was then drained on a grill, dried in vacuum at 70° to 80° C., and finally sifted in a rotary sieve to remove the dust.

The processes used in the manufacture of the various poison gases may be briefly outlined.

Mustard gas, or $B_1B'$ dichlorethyl sulphide, was manufactured from common grain alcohol. Ethylene was obtained by passing alcohol vapor over aluminum oxide at a temperature of 380° to 400° C. Ethylene chlorhydrin was prepared by passing carbon dioxide and ethylene into an aqueous solution of chloride of lime. By reaction with sodium sulphate, the chlorhydrin was changed to $B_1B'$ dihydroxy ethyl sulphide; this compound was converted into mustard gas by treatment with hydrogen chloride. The mustard gas was used as a solution in either chlorbenzene or carbon tetrachloride.

Perchlormethyl formate, also called trichlormethyl chlorformate, diphosgene, or superpalite, was manufactured by two processes. Methyl formate was made in the usual way, then chlorinated under the influence of high candle power lights with osram filaments. Or methyl chlorformate was prepared by the reaction of phosgene (carbonyl chloride) and methyl alcohol, and was then chlorinated.

The raw materials for the manufacture of diphenylchlorarsine or blue cross gas were aniline and arsenous oxide. The diazotized aniline hydrochloride was permitted to react with sodium arsenite in the presence of cupric sulphate to obtain the sodium salt of phenylarsenic acid. This acid was liberated by addition of hydrochloric acid, then reduced to phenylarsenous acid by use of sulphur dioxide. The sodium salt of phenylarsenous acid was next condensed with diazabenzene chloride to obtain sodium diphenylarsenate, which yielded diphenylarsenic acid when treated with hydrochloric acid. The diphenylarsenic acid was reduced to diphenylarsenous oxide by means of sulphur dioxide. This oxide was immediately converted into diphenylchlorarsine by hydrochloric acid, which had been added to the reaction mixture.

Diphenylcyanarsine was made by treating diphenylchlorarsine with either sodium cyanide or potassium cyanide.

In the manufacture of ethyldichlorarsine, ethyl chloride was made to react with sodium arsenite to obtain sodium ethylarsenate. The solution of this salt was made neutral, treated with an excess of sulphur dioxide, and heated to 70° C. The ethylarsenic acid was reduced to ethylarsenous acid, then converted into the anhydride of the latter, *i.e.,* ethylarsenous oxide. This oxide was changed into ethyldichlorarsine by treatment with hydrogen chloride.

Phenyliminophosgene was made by the action of chlorine on phenyl mustard oil.

Symmetric dichlor methyl ether was obtained by the action of chlorsulphonic acid on either paraformaldehyde or an aqueous solution of formaldehyde in the presence of sulphuric acid and water. Symmetric dibrom ethyl ether was manufactured in exactly the same manner except that ammonium bromide was substituted for chlorsulphonic acid.

Bromacetone and brommethylethyl ketone were made from acetone and methylethyl ketone respectively by treatment with bromine and chlorate of either sodium or potassium in aqueous solution.

Xylyl bromide was prepared by bromination of xylene, chlorpicrin by the reaction of picric acid and bleaching powder.

Phosgene was obtained by the union of carbon monoxide and chlorine in the presence of a carbon catalyst, which was prepared from wood charcoal by treating with hydrochloric and other acids until entirely free from soluble ash, washing, and drying in vacuum. Animal charcoal yielded an even better catalyst. The charcoal was used in fragments of approximately one-fourth inch mesh, and retained its catalytic activity for about six months. The carbon monoxide was prepared by passing carbon dioxide over charcoal in gas-fired muffles and washing with sodium hydroxide.

The average monthly production in tons, of certain of these poison gases was:

| | |
|---|---|
| Mustard gas | 300 |
| Diphosgene | 439 |
| Diphenylchlorarsine | 150 |
| Ethyldichlorarsine | 78 |
| Phosgene | 318 |
| Phenyliminophosgene | 65 |
| Dichlormethyl ether | 26 |
| Dibrom methyl ether | 7 |
| Chlorpicrin | 245 |
| Xylyl bromide | 55 |
| Bromacetone plus Brommethyethyl ketone | 19 |

J. S. H.

**Solar Constant of Radiation.** C. G. ABBOTT. (*Proc. National Academy of Sciences*, September, 1919.)—The quantity of energy from the sun, incident in one minute upon one square centimetre of surface, at mean distance from the sun, outside the earth's atmosphere and placed perpendicular to the direction in which the radiation moves, is called the Solar Constant of Radiation. For fourteen years the Smithsonian Astrophysical Observatory at Mount Wilson, Calif., has been studying this constant. One result is that it turns out to be no constant at all. From day to day it changes, proving the sun to be a variable star. There are two super-imposed variations, one with a range of from 3 per cent.

to 5 per cent., extending over the period of the sun-spot cycle, the other being irregular and having periods of months or days with a range of occasionally as much as 10 per cent.

Observations in Algeria in 1911 and 1912 confirmed the Californian results. Since 1918 an expedition has been measuring the constant in Chile, at an altitdue of 7500 feet, in a very cloudless region. It is found that at Mount Wilson and at Calama, Chile, in different hemispheres and 5000 miles apart changes in the quantity of radiation received from the sun keep step with each other. Furthermore, a connection has been established between variations in solar radiation and weather conditions on the earth. The Argentine government is employing radiation data from Calama in forecasting the weather.

Observations at both stations showed that the solar radiation was greater than the average in 1918, equalling 1.95 calories per minute. The average value is 1.93. G. F. S.

**Alcohol as a Motor Fuel.**—Reference was made recently in a note in this JOURNAL to the importance of investigations for securing cheap methods of production of alcohol suitable for use in internal combustion engines. The supply of petroleum products, while abundant, is not inexhaustible, and as alcohol is obtainable from vegetable substances, there is no practical limit to the supply. At present, the cost of production is the only serious bar to its extensive use. The use of gasoline is increasing at a rapid rate. The following figures taken from an article in *The Engineer* (1919, vol. cxxviii, p. 17) show in round numbers the consumption of gasoline in the United States for the past few years:

| Year | U. S. Gallons | Increase |
|---|---|---|
| 1914 | 1,440,000,000 | |
| 1915 | 1,680,000,000 | 240,000,000 |
| 1916 | 2,000,000,000 | 320,000,000 |
| 1917 | 2,780,000,000 | 780,000,000 |
| 1918 | 3,210,000,000 | 430,000,000 |

The reduction in the rate of increase from 1917 to 1918 is doubtless due to the restriction of private use under the government appeals, as in the case of the "gasless Sundays." It is almost certain that 1919 will show a great increase over 1917.

Influenced by the importance of the problem and by the fact that Great Britain must obtain a large part of its gasoline or other hydrocarbon fuel from other countries, the British government appointed a commission to investigate the alcohol question. The report of this commission has just been published. Some of the data are given in the issue of *The Engineer* above quoted.

It is pointed out that not only will the demand for ordinary motor cars, pleasure or commercial, be constantly increasing, but

the development of the airplane and dirigible will add enormously to the requirements. If alcohol can be substituted in large part for the other hydrocarbon fuels it will be possible to establish stations for its manufacture at or very near to the stations of the air lines, thus materially diminishing the expense of handling the fuel.

It is stated that a great deal of molasses goes to waste, which might be utilized as a source of alcohol. One ton of potatoes (2240 pounds) yields 24 (U. S.) gallons of 95 per cent. alcohol. Peat has not yet been successfully used. Reference is made to a tree that grows in the central India region, the flowers of which contain considerable amount of fermentable sugar. According to the report, the sun-dried flowers contain 60 per cent. of this, and ought to yield somewhat over 100 (U. S.) gallons per long ton. It does not seem likely, however, that a tree flower could be obtained in sufficient abundance to affect materially the supply of alcohol.

The commission recommends a search for cheap denaturants or those which are effective in very small amount (suggesting formaldehyde as one of the latter) and points out that much of the strictness of the revenue laws will have to be relaxed if a cheap fuel is to be obtained. It also recommends that all industrial alcohol should be sold with indication of its percentage of ethyl hydroxide. One advantage of alcohol as a fuel is that it will be practically uniform in efficiency wherever obtained.

H. L.

**Analysis of Photographs of Fog Signals Obtained with the Phonodeik.** D. C. MILLER. (*Trans. Royal Society of Canada*, March, 1919.)—The source of the signals was a Northey diaphone at Father Point Station, Quebec. Photographs were made by the phonodeik, one of Professor Miller's own devices. A horn directs the sound waves upon a sensitive diaphragm whose vibrations are transmitted to a small mirror. A beam of light is reflected from this and falls on a moving photographic film. As the mirror vibrates the reflected beam moves correspondingly and a sinuous trace of the sound wave is produced on the film.

Records were taken at different distances over water in front of the fog-signal and also on the land away from the axis. By means of the apparatus described in the JOURNAL OF THE FRANKLIN INSTITUTE, January and September, 1916, the curves were analyzed into twenty or even thirty components and the results of the analysis were proved by synthesis. The effective frequency of the fog-signal was 174 per second, though a note an octave below was always present. The analysis gives the amplitude of this lowest component and of 19 harmonics. When these were combined they reproduced the curve actually photographed by the phonodeik.

The relation between the amplitudes of the several overtones

varies greatly, changing with distance from the source. The higher harmonics are always feebler than the lower group and disappear entirely at about two miles from the signal. A study of the intensities of the harmonics shows that the master-tone, 174 in frequency, carries best of all to distances of two miles or more, though the octave above it exceeds it at 1100 feet nearer the source. The inverse square law of decrease of intensity was found to be invalid.

When a horn was used on the fog-signal and photographs taken away from the axis, the higher harmonics were not relatively so strong as they were along the axis. An increase in the air pressure used in blowing the diaphone resulted in an increased acoustical output. Elevating the air pressure caused those tones which had the greatest carrying power to increase in intensity more rapidly than the others. G. F. S.

**French Railways, Highways and Canals After the Invasion by the Huns.** (*Genie Civile*, April 5 and September 27, 1919.)—In a report made to the President of France, March 21, 1919, it is stated that the following losses were inflicted upon the railroads of France during the war: 5600 km. of single track line, 1510 bridges, 12 tunnels and 590 buildings. To render the tracks useless the Huns employed a crude but effective plow of rails dragged along the road-bed by a locomotive. Some hundreds of mines calculated to explode after a long interval were left in place. The seriousness of the situation was shown by the fact that of the seven lines formerly connecting Paris to Alsace-Lorraine only one was left in operating condition. Fifty thousand freight cars were lost by France in August, 1914. At the beginning of the present year great numbers of locomotives, freight cars and passenger cars were awaiting repair. Highways. One hundred and five thousand kilometres of roads were in need of more or less considerable repair. Canals. The work of destruction embraced 450 bridges, 115 locks and 1075 km. of canals or canalized rivers.

The later number of *Genie Civile* renders due credit to the assistance of the British and the American troops and presents an encouraging report of the state of the repair work. In the railroad systems of the north by September 1, 1919, all of the single track lines and all but 6 km. of the double track lines have been restored. Only four (4) of the destroyed stations remain to be cleared away, one viaduct has been put anew in service and others were nearing completion. In the system of the east more remained to be done.

The canal system has been restored to a surprising extent. Paris is again connected to the coal fields of the north by internal water-ways, and also with the east. Electric traction to transport the coal from the Sarre basin is to be installed on the Marne-Rhine Canal.

Much work has been done in road repair. Bridges amounting in length to a total of 4 km. have been put in position. Seven thousand kilometres of roads have been restored, but much repairing awaits the future.

G. F. S.

**Safety in a Steel Plant.** H. P. HEYNE. (*National Safety Council,* 1919.)—Each establishment should have its system of shop discipline, but there are ways in which the emplyees can better inform themselves regarding what is expected of them, through the inauguration of a systematic program for conducting the work.

The new way to put safety across in any plant, is to meet the problems with a better understanding of affairs, and an assurance of fairness between the foremen and the employees, which should furnish the material for erecting the foundation for the coöperative spirit which the coming era is ushering in.

The two factors which bind men together are fellowship and good-will, based on mutual confidence. These are indispensable in attaining unity of purpose on the part of all for the welfare of all.

A. R.

**Further Notes on Alcohol as Fuel.** (*Bulletin 245, Am. Chem. Soc. News Service.*)—King Alcohol was hailed as a new monarch of the realm of power in a symposium held Friday, October 10, by the New York Section of the American Chemical Society. The five well-known chemists who addressed the section told of new sources of alcohol which could be tapped and indicated many new uses for it.

B. R. Tunison said that probably ten times as much alcohol as was consumed before Prohibition days would eventually be utilized by the American people, albeit, they have decided to dispense with it as a beverage. In a normal year the United States drank 160,000,000 gallons of alcohol and used approximately 100,000,000 gallons in the various arts. Among the sources which could be developed is the nipa palm which flourishes in the Philippines and other tropical countries, and yields, said Mr. Tunison, about 15 per cent. of sugar which could be fermented. From that source alone 50,000,000 gallons a year could easily be produced. The Mexicans brew a fiery beer from the sotol plant, a variety of agave which exists in very large quantities in their country from which millions of gallons could be distilled. By changing the cellulose of sawdust and other wood waste into sugar and then fermenting that substance, plenty more alcohol can be obtained. It is identical with that derived from grain and is quite different from the methyl or so-called wood alcohol of the "Pink Elephant" brand which is made by another process. Considerable alcohol can also be derived from the waste of gas works.

In order to bring all these alcohols within the domain of the law they have been denatured or treated in such a way as to make them unfit for human consumption. There are now about forty denaturing formulas which are approved by the Internal Revenue Bureau. The Government puts on a tax of $4.15 a gallon on straight alcohol even if employed for industrial purposes. Undrinkable alcohols are used as solvents in the various chemical industries and especially in the development of the rapidly growing dye-industry. They can serve well in the manufacture of rosins as a solvent and by their use a perfectly transparent product can be manufactured.

Mr. Tunison prophesied that as the petroleum supply decreases and the price of gasoline is therefore raised, alcohol will come into greater use as a motor fuel. Denatured ethyl alcohol, identical in composition with that distilled from grains, is now cheap in car-load lots, and there are compounds of it which are sold even now for only a few cents more a gallon retail than the price of gasoline. Mr. Tunison said that these new alcohol fuels yield more power to the gallon than does gasoline and do not clog carburetors. There is also a demand for the so-called solidified alcohol which is made by adding paraffine and such substances to spirits.

F. W. Kressmann gave details concerning the manufacture of "Ethyl Alcohol from Wood Waste." G. F. Richmond told of the possible increased use of the so-called "Higher Alcohols" which are employed in the manufacture of extracts and perfumes. Ralph H. McKee spoke of "Alcohol from Sulphite Wood Waste," and Leonard H. Cretcher's topic was "The Use of Alcohol in the Dye Industry."

**Tanks in Warfare.** (*Society of Automotive Engineers*, 1919.) —There is no doubt of the great value of tanks in warfare. They are an answer to the machine gun. As in other automotive vehicle design the questions which arise in formulating specifications for tanks relate to overall size, amount of internal space, power, capacity and running speed. There are, of course, numerous other matters involved by virtue of the characteristics of tank operation, such as balance and ground pressure. The power plant is obviously a vital feature of the tank. The tank now has one-man operation as a feature, whereas several men were required to drive the first European models. Generally speaking, it is to be expected that tanks and tractors will not only be equipped with various types of accessories developed and to be developed, but be lighter, faster and less noisy. One interesting phase of tank construction is the feasible life of the machine under strenuous conditions so far as the power plant is concerned. There is no doubt that the task of an engine in a large tank is a very severe one. Our Army had, however, a goodly number of tanks

in operation for a considerable time during the war and these were right at the front when the Armistice was signed. The tanks are not an independent arm of the service in that they require infantry support. One of their particular functions is to clear the way for the infantry, especially with regard to enemy machine guns. There is no doubt that the tanks are a decidedly effective humane element in the saving of men in war engagement.

A. R.

**Suez Canal Business During the War Period.**—While the international agreement under which the Suez Canal is operated prohibits its being blockaded, the state of war influenced materially the traffic through it, particularly in view of the activity of the submarines of the Central Powers. As the German-Austrian surface navy was practically swept from the seas in the early days of war, it is probable that if submarine activity had not occurred but little difference would have been found in the canal traffic. The data for 1918 in comparison with those for 1912, for instance, show a falling off of over 50 per cent. in number of ships, and somewhat less than the same percentage in total tonnage. Notwithstanding the concentration of submarines on the English commerce, the canal traffic under the English flag was, during 1918, over 79 per cent. of the total. Throughout the years, England has led by a large margin, Germany being second. German tonnage, of course, disappeared, and that of Holland which was third in 1912 fell to a single ship of less than 5000 tons. The falling off of the Dutch tonnage is probably due to the diversion of the East India traffic to the Cape of Good Hope route for safety. Italy and Japan have increased somewhat their canal tonnage, but may not be able to hold their relative position when England recuperates. The United States tonnage is, as might be expected, quite small; for some recent years less than half a dozen ships a year, with a total tonnage of less than 10,000. Comparative statistics show that the average tonnage per vessel has been, as a rule, increasing.

H. L.

**Starch-dust Explosions.**—In some investigations of the phenomena of dust explosions at the plant of the Bureau of Mines near Pittsburgh, a very unexpected result was obtained. The plant consists of a steel cylinder, 225 feet long set above ground, intended as a counterpart of a mine gallery. The upper part of the pipe has at certain intervals, ports provided with lids. The progress of an explosion can be watched by the jets of flame and smoke that appear at the vents. Lately, motion pictures have been taken of the phenomena, more particularly for use in campaign for prevention of grain-dust explosions. After experiments with coal-dust, in which rather violent explosions were produced,

the cylinder was cleaned and flour-dust exploded. The blast was far more violent than that from the coal-dust, and startled the engineers. Starch-dust was then used.

During each of the first two blasts the operator was somewhat shaken by the detonation, but the shocks were relatively light and their effects little more than temporary. With the setting off of the starch charge, however, the earth seemed to tremble, the booth rocked on its foundation, and reports received later showed that houses two and three miles away were shaken. The concussion shattered the glass in the walls of the camera booth. The operator was temporarily blinded and almost stunned, but his long training in his profession kept him turning the crank of his camera even as it swayed to and fro in its shelter. All of this upheaval took but an instant of time. Climbing out from the broken booth the operator looked about and found that some of the engineers, who had stood at a considerable distance to witness the test, had been thrown to the ground. As soon as they recovered their senses and equilibrium they ran to the camera booth, fearing that the operator had been killed.

While no one received serious injuries, the experiment was one which no one is anxious to go through a second time. Examination of the Bureau of Mines' equipment showed that the concrete foundations had been shattered by the violence of the blast and part of the shelves within had been blown out and reduced to kindling, while the target or deflecting screen which stood at some distance from the open mouth of the cylinder, had been partly torn from its deeply laid foundations. Motion-picture men state that in the whole history of the industry, few movie views of this sort have been taken under such hazardous circumstances.

H. L.

**De-lousing Experiments.**—Every one knows the serious aspect of the louse question in army hygiene. While those who were far from the trenches were occasionally humorous about the "cooties," those who had to deal with them saw no joke. The subject has an industrial as well as military bearing, for the insect is known to be a carrier of several diseases. It is pretty well established that in Serbia typhus fever was mainly propagated by lice. Human beings are infected with three forms of lice, but the most important one is the body louse (*Pediculus corporis*). A scientific investigation of the methods of ridding clothing of these was undertaken by Wm. Moore, B.A., and Arthur D. Hirshfelder, M.D., both of the faculty of the University of Minnesota. The work is far from agreeable, but the investigators, with others, including students of the University, pursued faithfully their labors. Lice were reared in great numbers in incubators and fed on human blood, as many as 4000 having been fed at one time on the forearm of one person.

The pamphlet of 86 pages, 8vo., gives the details of the experiments, and an extensive bibliography. The conclusions are as follows:

1. Lice may be reared under incubator conditions in large numbers, if fed with human blood twice daily, but under such conditions the life cycle is slowed down, and the daily and total egg production per female is reduced.

2. Fever, rash, and a general lassitude are produced as a result of louse bites.

3. Lice and their eggs are destroyed by the ordinary laundering processes used in the washing of cotton and khaki goods; for woolens slight alterations in the methods of washing are necessary.

4. Chlorpicrin may be used for fumigation of garments, accomplishing the desired results in a short period, with a small quantity of the chemical, without the use of high temperatures.

5. The sachet method of controlling lice is ineffective or very expensive.

6. Louse powders may be used with success but, being a wasteful method of applying an insecticide, are not recommended.

7. Impregnation of the underwear is the most promising method of louse control between lousings. Active chemicals of very low volatility are necessary to prove effective for the longest period of time. Halogenated phenols, such as dibrometacresol, dichlormonobrometacresol, and their sodium salts, dibromcarvacrol, and dibromxylenol were found to be the most promising under laboratory conditions. H. L.

**New Food Oil from Grape Seed.** (*Am. Chem. Soc. News Service.*)—From the grape seeds is being derived a new food oil. It is pressed from the seeds which formerly were discarded. This by-product has been found edible and nutritious. It may become a rival of olive and cottonseed oils for cooking and salad dressing.

Dr. J. H. Shrader, of the Bureau of Plant Industry, of the U. S. Department of Agriculture, has made extensive investigations in the commercial utilization of grape seed. In a paper read before the Division of Industrial Chemists and Chemical Engineers, of the American Chemical Society, he suggested that all waste of this character from the vineyards and canneries be assembled at a centre, so that there will be enough tonnage to make its fabrication profitable. He said:

"In the grape-juice industry the grapes are pressed in ordinary cider presses to obtain the juice. The skins, seeds and pulp remain behind in the cloths. The total tonnage of grapes pressed for juice in the grape belts of New York, Ohio and Michigan was ascertained directly from the firms for each of the past five years in order to strike a fair average. From these figures a pomace yield of 20 per cent. was calculated, which in turn yielded one-quarter seed, one-quarter dry skins, and one-half water.

"A method has been worked out and operated in the laboratory on a semi-commercial scale whereby grape seed can be separated from wet grape pomace without recourse to drying. The seed separation will enable the producer to take out his seed from the balance of the waste at each pulping and pressing station. This makes him independent of the necessity of shipping all of his waste to the central plant."

Because of the shortness of the grape-juice pressing season, which lasts from September to November, estimates have been made on a plant only large enough to dry the maximum amount of seed and then press it in winter months. A charge of $9 per ton of raw material is allowed for drying and handling from freight cars to storage bins, while $15 to the ton of dry grape seed is allowed for expelling the oil and handling from the seed storage to the oil in tanks. This would include all overhead and management charges, except rent of property or interest on real estate investment.

Doctor Shrader believes that the efficiency of these plants could be increased by also extracting the oil from the seeds of tomatoes, as a great many such seeds are rejected in the making of catsup and in canning. Seeds from pumpkins and those from other vegetables can also be utilized.

**Gas-masks for Ammonia.**—Messrs. PERROTT, YABLICK and FIELDNER, of the Chemical Warfare Service (*J. Ind. Eng. Chem.*, vol. xi, 1919, 1015), describe a new form of gas-mask, especially adapted to the protection of workmen in industries in which refrigerating plants are operated. They point out that the usual method which employs pumice drenched with sulphuric acid has several objectionable features, among which are production of much heat by the absorption, high initial resistance, and the necessity for a canister capable of resisting corrosion. Caustic fumes are also produced which must be stopped by a pad, thus increasing the difficulty of breathing. They experimented with salts having the property of combining with ammonia, and give preference to pumice stone saturated with copper sulphate. This was shown to have a great capacity of absorption. A canister containing 45 cubic inches of this material will protect a man, breathing at rest, for five hours against an atmosphere containing 2 per cent. of ammonia and for two and one-half hours in an atmosphere containing 5 per cent. Tests at high breathing show that protection is ample at great exertion. Several other substances are efficacious, among which are cobalt chloride, boric and silicic acids. The copper sulphate method has the advantage of large capacity of absorption, low heat disengagement and cheapness.

In this connection, note should be made of a statement from the British Home Office (For. Ind. News, *J. Ind. Eng. Chem.*, vol. xi, 1919, 1064) that the ordinary army masks do not serve as

protection in dealing with mine fires, or entering the mine after explosions. The atmosphere in such cases contains a good deal of carbon monoxide, against which the ordinary charges of the mask are inert, and further, there is often a decided diminution of the proportion of oxygen, which may in itself be a great danger. Inasmuch as the masks protect against smoke, they give a feeling of security to a person entering the smoky air and thus add to the likelihood of his being overcome.

H. L.

**Application of Fish-oils in the Paint Industry.** (*Paint Mfrs. Assn. Circ.* No. 74.)—Several fish-oils have long been used in the manufacture of soap, leather and for hydrogenation. Tests have been made of four fish-oils—grayfish, shark, fur-seal and skate—with a view to determine if any of them can be used as drying oils, but the results were negative. Incidentally, it has been shown that, as regards these oils, at least, the iodine number is not an index of the drying qualities, for the fish-oils showed numbers from 135 to 151, but possessed much less drying power than some vegetable oils (soy bean and cottonseed), having figures as low as 120 to 130.

From a sample of shark liver oil a notable amount of an unsaturated hydrocarbon was extracted. The presence of this was indicated by the low saponification number and the large amount of unsaponifiable matter. The hydrocarbon was a pale yellow liquid without pronounced odor. A hydrocarbon of somewhat similar character was isolated a few years ago from the livers of species of sharks in Japanese waters by Mitsumaru Tsujimoto.

H. L.

**A New Seed-oil.** (*Paint Mfrs. Assn. Circ.* No 72.)—The oil from the seeds of *Calophyllum inophyllum*, a hardwood tree of the Philippines, known locally as Palo Maria, has been examined with a view to its applicability to the paint industry, but the results are not satisfactory, and it is evident that it must be subjected to some special treatment to give it rapid drying properties. The oil is not serviceable for food as it contains a poisonous resin, to which the color and odor are due. It is, however, used in its native regions as an application in skin affections. The fatty acids yielded by it are principally palmitic, oleic and stearic, so that it would serve well as a source of soap and glycerol.

H. L.

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